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CHRYSANTHEMUM : THE QUEEN OF AUTUMN BLOOMS – AN OVERVIEW

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ABSTRACT

Chrysanthemum (*Chrysanthemum* × *morifolium* Ramat.), popularly known as Guldaudi, stands as the "Queen of Autumn Blooms," celebrated for its vibrant diversity, ornamental beauty, and profound cultural symbolism. Beyond its aesthetic appeal, it holds immense economic and scientific significance as a model crop in global floriculture. This review synthesizes comprehensive insights into the taxonomy, morphology, propagation, breeding, and production technologies of chrysanthemum, with emphasis on recent advances in mutation breeding, molecular markers, tissue culture, and genome editing. The article highlights India's evolving chrysanthemum sector in comparison to global trends, discussing varietal development, post-harvest management, and sustainability-driven innovations. Additionally, the phytochemical richness and medicinal potential of certain species underscore its multifaceted value. Integrating traditional cultivation wisdom with biotechnological innovations can transform Guldaudi into a sustainable pillar of modern ornamental horticulture and rural livelihood enhancement.
Keywords **:** Chrysanthemum, Guldaudi, Breeding, Biotechnology, Floriculture, Micropropagation, Sustainability

Introduction

When autumn arrives and most blossoms surrender to the fading light, *Guldaudi* (Chrysanthemum × morifolium Ramat.) emerges in regal splendour-adorning landscapes, gardens, and festive spaces with its dazzling shades of gold, white, pink, purple, and crimson. Known globally as the Queen of Autumn Blooms, chrysanthemum symbolizes longevity, purity, and devotion. In China, it represents endurance and nobility; in Japan, it is the national flower symbolizing joy and the Imperial family; and in India, it embodies faith, festivity, and prosperity, forming a vital part of cultural and religious expressions.

The genus *Chrysanthemum* belongs to the family *Asteraceae* and includes around 200 species, native to East Asia, primarily China and Japan (Perveen & Qureshi, 2022). Over centuries, extensive breeding, hybridization, and mutation have produced thousands of cultivars differing in color, form, fragrance, and photoperiodic response. *Chrysanthemum* × *morifolium*, a complex hybrid species, dominates global commercial production, reflecting its extraordinary adaptability and aesthetic diversity (Jiang *et al*., 2021).

Globally, chrysanthemum ranks second only to rose in cut flower production and holds an unmatched position in the loose flower market (AIPH, 2024). It contributes substantially to the ornamental plant trade, both as a cut flower and pot plant, and serves as a major export commodity in countries such as China, Japan, the Netherlands, and South Korea. The International Statistics Flowers and Plants 2024 report indicates that chrysanthemum accounts for nearly 18–20% of global ornamental plant turnover, highlighting its commercial dominance.

In India, *Guldaudi* occupies a unique place that transcends commercial floriculture. It is grown extensively across states such as Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, and West Bengal, covering both open-field and protected environments.

The flower is a staple of Indian festivals, religious ceremonies, and garland-making, particularly during Diwali, Dussehra, and Navratri. Loose flowers of chrysanthemum are traded in major flower markets such as Bangalore, Pune, and Kolkata, ensuring year-round demand (Kumar *et al*., 2023).

Beyond its cultural and aesthetic role, chrysanthemum is valued for its phytochemical composition, which includes flavonoids, essential oils, and antioxidants. Certain species like *C. indicum* and *C. morifolium* are used in traditional Chinese and Ayurvedic medicine for their anti-inflammatory, antimicrobial, and sedative properties (Li *et al*., 2022). This dual ornamental and medicinal relevance enhances its potential for sustainable diversification in the global floriculture industry.

From a botanical viewpoint, chrysanthemum displays remarkable morphological and genetic plasticity. Its composite inflorescence, consisting of ray and disc florets, offers vast scope for color and shape variation. Mutation breeding and somaclonal variation have yielded popular forms such as spider, spoon, pompon, anemone, and decorative types. Moreover, the flower's adaptability to photoperiod manipulation allows off-season production, making it a vital species in controlled-environment floriculture (Jiang *et al*., 2021).

Aesthetically, the diversity of chrysanthemum has inspired art, poetry, and cultural symbolism across civilizations. In Japan, the "Festival of Happiness" (Kiku Matsuri) celebrates the bloom; in China, it appears in classical literature as a metaphor for integrity and endurance. India, meanwhile, venerates Guldaudi for its association with devotion and divine offerings, reflecting the flower's seamless integration into everyday life and spirituality.

Recent advances have highlighted chrysanthemum's potential contribution to sustainable floriculture. Its moderate input requirements, tolerance to abiotic stresses, and compatibility with organic and protected cultivation systems make it an environment-friendly crop. Moreover, genetic studies have identified accessions resilient to salinity, heat, and water stress, aiding adaptation under climate change (Chen *et al*., 2023). The use of eco-friendly production practices-including bioregulators, LED lighting, and hydroponic systems-has further expanded its relevance to green urban landscapes and vertical gardening (Wu *et al*., 2023).

In the context of India's growing floriculture export market, *Guldaudi* serves as a bridge between tradition and modernity-a flower that blends cultural heritage with scientific innovation. With appropriate varietal development, post-harvest management, and value addition, it can substantially enhance farmers' income while contributing to the aesthetic and ecological balance of urban and rural ecosystems.

Hence, rediscovering the splendour of this autumn queen is not merely a tribute to its beauty but a strategic step towards sustainable ornamental horticulture.

Global Scenario

Chrysanthemum (*Chrysanthemum* × *morifolium Ramat.*) has achieved a premier position in the global floriculture industry, ranking second only to rose in terms of production and trade value (AIPH, 2024). It is cultivated in more than 70 countries, with Asia and Europe being the primary production hubs. The flower's adaptability to diverse climatic conditions, its photoperiodic flexibility, and wide varietal diversity make it suitable for both temperate and subtropical regions.

China stands as the world leader in chrysanthemum cultivation and export, accounting for nearly 70% of global production and over 60% of total chrysanthemum exports (Frontiers in Sustainable Food Systems, 2025). The country's dominance arises from its rich genetic diversity, centuries-old breeding history, and the integration of modern biotechnology. Chinese breeders have developed thousands of cultivars suited for cut flowers, potted plants, landscaping, and medicinal use (Chen *et al*., 2023). Additionally, the Chinese government has promoted floriculture through policy initiatives emphasizing high-value ornamental crops, contributing significantly to rural income diversification.

In Japan, chrysanthemum enjoys both cultural and economic prominence. It is the national flower and the emblem of the Japanese Imperial Family. The country has established advanced cultivation systems emphasizing protected cultivation, precise temperature control, and photoperiod management, ensuring consistent supply throughout the year (Jiang *et al*., 2021). Japan also conducts extensive research on post-harvest longevity, color stability, and fragrance enhancement, targeting high-end export markets.

The Netherlands, despite its smaller land area, remains the centre of global chrysanthemum marketing and innovation. Through the *FloraHolland Auction System* and the use of automated greenhouse production, Dutch growers have achieved remarkable productivity. *Dutch chrysanthemum varieties* are globally known for uniformity, vase life, and disease resistance (AIPH, 2024).

Other important producers include South Korea, Italy, Colombia, and Kenya, which have recently expanded chrysanthemum exports to Europe and the Middle East (Li *et al.*, 2022). Advanced technologies such as LED-assisted flowering control, hydroponic systems, and mutation breeding are revolutionizing the crop's production and aesthetic appeal worldwide.

In the international cut flower trade, chrysanthemum accounts for approximately 18–20% of total global ornamental plant turnover, valued at over USD 3.8 billion annually (AIPH, 2024). Increasing consumer demand for eco-friendly and long-lasting blooms has driven the development of post-harvest treatment protocols and genetic improvements targeting extended shelf life and stress resistance (Wu *et al.*, 2023; Song *et al.*, 2023).

Indian Scenario

India has a long-standing cultural association with *Guldaudi*, reflected in art, rituals, and festive traditions. In modern times, this heritage has transformed into a thriving commercial floriculture sector. According to the National Horticulture Board (NHB, 2024), chrysanthemum occupies an area of approximately 30,000–35,000 hectares, contributing around 12% of India's total loose flower production.

Major chrysanthemum-producing states include Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, West Bengal, and Uttarakhand, where both cut and loose flower types are cultivated under open and protected conditions. Karnataka alone contributes nearly 40% of national output, supported by favourable agro-climatic conditions and access to major flower markets such as Bangalore and Hosur (Kumar *et al.*, 2023).

Indian chrysanthemum cultivation is predominantly based on loose flower types, suited for garlands, religious offerings, and decorative purposes. Varieties such as *Local White*, *Yellow Star*, *Raja*, *Jaya*, and *CO-1* are popular among Indian growers. In recent years, cut flower varieties developed by institutions such as IIHR Bengaluru and IARI New Delhi (e.g., *IIHR-6, Pusa Sona, Pusa Aditya*) have gained popularity for domestic and export markets.

Technological advancements, including photoperiod management, pinching, disbudding, fertigation, and growth regulator applications, have led to significant improvements in flower yield and quality (Rao *et al.*, 2023). Protected cultivation under polyhouses and shade nets has enabled year-round production, especially in peri-urban zones near Delhi, Pune, and Hyderabad.

Despite these advances, the Indian chrysanthemum industry faces challenges such as varietal degeneration, lack of uniform planting material, pest infestations (Aphids, Leaf miners, Thrips), and inadequate post-harvest infrastructure (Sharma & Saini, 2022). However, ongoing research and extension programs under ICAR institutes and State Agricultural Universities aim to address these issues through micropropagation, tissue culture-based nurseries, and integrated pest management (IPM) strategies.

The export potential of Indian chrysanthemum remains largely untapped. With improved cold chain facilities and quality certification systems, India can emerge as a major player in the Asia-Pacific chrysanthemum trade, particularly targeting markets in the Middle East and Southeast Asia. The integration of traditional floriculture with modern biotechnology and sustainable practices offers a transformative pathway for the Indian ornamental sector.

Comparative Insights

While global chrysanthemum production is driven by high-tech protected systems, automation, and market-oriented breeding, India's progress hinges on low-cost technologies, indigenous cultivars, and labour-intensive management. However, India holds an advantage in year-round climate suitability, low production cost, and rich genetic diversity, which can be leveraged for export-oriented growth.

Strategic collaborations between Indian research institutes and international floriculture centers can accelerate varietal development and improve post-harvest technologies. The rising domestic demand for aesthetic and decorative flowers, coupled with the government's "Floriculture Mission" and "Atmanirbhar Krishi" initiatives, signals a promising future for chrysanthemum cultivation in India.

Ultimately, *Guldaudi* exemplifies the perfect blend of cultural legacy and commercial potential-a flower that not only beautifies but also sustains livelihoods and represents India's evolving floricultural identity on the global stage.

Botanical Description, Morphology, and Taxonomy of Chrysanthemum

Taxonomic Position and Evolutionary Lineage

The genus *Chrysanthemum* L., belonging to the family Asteraceae (Compositae), is one of the most diverse and economically important genera among ornamental plants. The modern cultivated chrysanthemum, *Chrysanthemum* × *morifolium* Ramat. is a complex hybrid derived primarily from interspecific crosses between *C. indicum* L. and *C. morifolium* and occasionally involving other wild relatives such as *C. zawadskii*, *C. erubescens*, and *C. nankingense* (Liu *et al.*, 2024).

Taxonomic Classification:

- **Kingdom:** Plantae
- **Division:** Magnoliophyta
- **Class:** Magnoliopsida
- **Order:** Asterales
- **Family:** Asteraceae
- **Genus:** *Chrysanthemum* L.
- **Species:** *Chrysanthemum* × *morifolium* Ramat.

The taxonomic delineation within *Chrysanthemum* has long been debated because of extensive interspecific hybridization, polyploidy, and morphological plasticity. The genus is closely related to *Ajania*, *Leucanthemum*, and *Dendranthema*. The latter was once proposed as a separate genus for cultivated chrysanthemums (*Dendranthema grandiflora*), but molecular phylogenetic studies based on nuclear and chloroplast DNA sequences reinstated the use of *Chrysanthemum* as the accepted nomenclature (Zhao *et al.*, 2022; Song *et al.*, 2023).

Morphological Characteristics

Chrysanthemum is an herbaceous perennial with remarkable variability in form, color, and inflorescence structure.

Habit and Root System

Plants are generally bushy, erect, and branched, ranging from 25 cm to over 1 m in height. The root system is fibrous, shallow, and well-developed, enabling quick regeneration after pruning or division (ICAR-IIHR, 2023).

Stem

The stems are cylindrical, somewhat pubescent, and green to reddish-brown in color, becoming woody at the base with age. Internodal length is influenced by cultivar, growth regulators, and light intensity.

Leaves

Leaves are alternately arranged, simple, lobed, and variable in size. They are often dark green, pinnatifid or serrated with irregular margins, and emit a characteristic aromatic odor due to volatile terpenoids (Noda *et al.*, 2023).

Inflorescence (Capitulum)

The characteristic "flower" of chrysanthemum is actually a composite head or capitulum, consisting of two types of florets-ray florets (peripheral, female or sterile) and disc florets (central, bisexual or fertile). The ray florets form the showy outer part, responsible for the color and form variation seen among cultivars. The receptacle is flat or slightly convex, and surrounded by involucral bracts arranged in several imbricate rows (AIPH, 2024).

Floret Types

Chrysanthemums exhibit enormous diversity in floret morphology-spoon-shaped, tubular, quilled, anemone, pompon, spider, and incurved types. The variation in petal shape and arrangement forms the basis for horticultural classification.

Fruit and Seed

The fruit is an achene, small, dry, and indehiscent. Seeds are light, angular, and capable of producing variable progeny due to cross-pollination and polyploidy. However, vegetative propagation (cuttings, suckers, tissue culture) is preferred to maintain varietal integrity (ICAR-IIHR, 2023).

Chromosome Number

The basic chromosome number in *Chrysanthemum* is $x = 9$, but cultivated forms are often hexaploid ($2n = 6x = 54$), and polyploidy plays a critical role in its morphological diversity and environmental adaptability (Chen *et al.*, 2023; Liu *et al.*, 2024).

Botanical Diversity and Classification of Cultivars

The cultivated chrysanthemum comprises an immense range of cultivars, often categorized based on flower form, size, and season of blooming. The National Chrysanthemum Society (UK) and ICAR-IIHR (India) recognize several distinct flower forms (Fig-1.)

Fig. 1: Flower forms of Chrysanthemum (1. Incurved, 2. Reflexed, 3. Intermediate, 4. Pompon, 5. Anemone, 6. Single, 7. Spoon, 8. Quill, 9. Spider, 10. Brush or Thistle, 11. Decorative, 12. Spray type)

The diversity of color ranges from white, yellow, orange, bronze, pink, red, purple, to bicolor and greenish shades-resulting from varying concentrations and ratios of anthocyanins, carotenoids, and flavonoids. Modern breeding programs focus on developing blue- and black-flowered chrysanthemums through genetic engineering and metabolic pathway regulation (Noda *et al*., 2023).

Cytogenetics and Molecular Insights

Molecular marker analyses (SSR, AFLP, and SNP markers) have revealed that modern *C.* × *morifolium* cultivars exhibit complex allopolyploid genomes with extensive interspecific introgression. Genome sequencing and QTL mapping studies (Wu *et al*., 2023; Liu *et al*., 2024) have identified several candidate genes involved in flowering time regulation (*CmFTL*, *CmSOC1*), pigment biosynthesis (*CmCHS*, *CmF3H*), and stress tolerance (*CmDREB*, *CmLEA*).

Recent CRISPR/Cas9-mediated gene editing has opened possibilities for precise trait improvement, such as enhancing vase life, fragrance modulation, and photoperiodic adaptability. Integration of transcriptomics, metabolomics, and phenomics has deepened understanding of the genetic control underlying floral diversity (Zhao *et al*., 2022).

Propagation and Production Technology

Propagation and breeding form the backbone of chrysanthemum improvement and commercialization. Because the cultivated chrysanthemum (*Chrysanthemum* × *morifolium* Ramat.) is a complex polyploid with extensive heterozygosity and self-incompatibility, breeding and propagation demand both conventional and advanced biotechnological interventions. The goal is to combine desirable traits such as novel flower color, longer vase life, pest and disease resistance, and photoperiodic adaptability

(ICAR-IIHR, 2023; Wu *et al.*, 2023). In India and abroad, a variety of propagation techniques-sexual, asexual, and tissue culture are employed to maintain genetic purity, rapid multiplication, and uniform flowering. Alongside, modern breeding strategies including molecular marker-assisted selection (MAS), induced mutation, and genetic transformation are expanding the horizons of chrysanthemum improvement (Liu *et al.*, 2024).

Methods of Propagation

Sexual Propagation

Seed propagation is rarely used in commercial chrysanthemum cultivation due to the plant's high heterozygosity, self-incompatibility, and segregation in progeny. However, it remains essential in breeding programs to generate genetic variability and develop new cultivars (Song *et al.*, 2023). Controlled pollination between selected parental lines is performed during the early morning when stigmas are receptive. Seeds are sown in sterilized media (soil:sand:FYM = 1:1:1) and transplanted after 3–4 weeks. The resultant progenies exhibit significant morphological and physiological variation that serves as raw material for selection.

Asexual (Vegetative) Propagation

Vegetative propagation ensures uniformity in commercial production. It is widely practiced through:

Terminal Cuttings

The most common and economical method. Softwood cuttings (5–7 cm) from healthy stock plants are treated with rooting hormones like IBA (1000–2000 ppm) or NAA (500–1000 ppm) and rooted under mist chambers at 20–25°C (ICAR-IIHR, 2023). Root initiation occurs within 15–20 days.

Suckers and Stolons

Some varieties produce natural offshoots or suckers that can be separated and transplanted. Although slower, this method maintains varietal fidelity.

Division of Clumps

A traditional method used in gardens for perennial varieties. After flowering, the mother plant is divided into smaller sections and replanted. Vegetatively propagated plants flower uniformly and maintain desired genetic traits, but the long-term use of the same stock plants may lead to viral accumulation-necessitating periodic rejuvenation through micropropagation or meristem culture (NHB, 2024).

Micropropagation and In Vitro Techniques

Micropropagation has emerged as an efficient, disease-free, and large-scale method of multiplication. Nodal segments, shoot tips, or leaf explants are cultured on MS medium supplemented with cytokinins (BAP 1.0–2.0 mg/L) and auxins (NAA 0.1–0.5 mg/L) to induce shoot proliferation (ICAR-IIHR, 2023).

Stages of micropropagation include:

1. ***Initiation:*** Surface sterilization and establishment of explants.
2. ***Multiplication:*** Shoot induction via cytokinins.
3. ***Rooting:*** In vitro rooting on auxin-enriched media.
4. ***Acclimatization:*** Gradual hardening in controlled shade conditions.

- Micropropagation not only allows rapid clonal propagation but also serves as a platform for in vitro mutagenesis, cryopreservation, and genetic transformation.
- Recent advances include temporary immersion bioreactors for scalable production and synthetic seed technology for storage and transport (Zhang *et al.*, 2024).
- *In vitro* culture from shoot tips and nodal segments ensures virus-free plants.
- Use of BAP (1–2 mg/L) and NAA (0.5 mg/L) promotes shoot proliferation.

Climate and Soil Requirements

Chrysanthemum thrives in mild, temperate climates with moderate humidity. It is a quantitative short-day plant that requires approximately 13–14 hours of photoperiod for vegetative growth and less than 12 hours to induce flowering (Kumar *et al.*, 2022). Optimum temperature for growth ranges between 20–28°C during the day and 10–15°C at night. High temperatures during bud initiation delay flowering and reduce flower size (Singh *et al.*, 2023).

Well-drained, fertile loamy soils rich in organic matter with a pH of 6.0–7.0 are most suitable. Heavy clay soils cause waterlogging and root rot, whereas sandy soils need frequent irrigation and organic amendments (Meena & Dutta, 2021).

Varieties and Cultivars

Chrysanthemum varieties are classified based on their use cut flower types, pot culture types, and garden display types. Popular Indian cultivars include *Pusa Centenary*, *Pusa Kesari*, *Pusa Sona*, *Pusa Chitraksha*, and *Little Darling*. For cut flower purposes, varieties such as *Reagan White*, *Reagan Pink*, and *Yoko Ono* are widely used in commercial floriculture (NHB, 2024). Recent breeding programs emphasize traits like long vase life, resistance to leaf spot and wilt, and novel flower colors. Genetic improvement is also achieved through mutation breeding, somaclonal variation, and marker-assisted selection (Patil *et al*., 2023).

Land Preparation and Planting

The land should be ploughed 2–3 times, followed by incorporation of 25–30 tons of FYM per hectare. Raised beds of 1–1.2 m width is preferred to facilitate drainage and air circulation. Terminal cuttings (5–7 cm) are planted on ridges or raised beds at a spacing of 30 × 30 cm for garden types and 45 × 30 cm for cut-flower types. Best planting time in North India is June–July, while in southern regions, August–September planting ensures better quality blooms (Rao & Bhat, 2022).

Nutrient Management

Balanced fertilization significantly influences plant growth, flower yield, and quality. The general fertilizer recommendation is 200 kg N, 100 kg P_2O_5, and 100 kg K_2O per hectare. Half of nitrogen and full doses of phosphorus and potassium are applied at planting, while the remaining nitrogen is top-dressed in two equal splits at 30 and 60 days after planting (NHB, 2024). Foliar sprays of micronutrients such as $FeSO_4$ (0.5%) and $ZnSO_4$ (0.3%) improve leaf chlorophyll content and flower coloration (Pandey *et al*., 2023). Organic amendments like vermicompost and biofertilizers (Azotobacter, PSB) also enhance soil health and flower longevity (Sarkar *et al*., 2022).

Irrigation Management

Chrysanthemum requires regular irrigation to maintain uniform soil moisture. The critical stages are vegetative growth and bud initiation. Over-irrigation causes root diseases, while moisture stress results in reduced flower size. Adoption of drip irrigation with fertigation ensures better nutrient use efficiency and water saving up to 40–50% compared to surface irrigation (Choudhary *et al*., 2022).

Pinching, Disbudding, and Training

Pinching encourages lateral shoot development and increases the number of flower-bearing branches. The first pinching is done 3–4 weeks after planting, and a second pinching after another 20–25 days depending on variety. Disbudding is essential in standard chrysanthemum types to retain one terminal bud per shoot for larger flowers, whereas in spray types, all buds are retained to produce multiple smaller blooms (Meena *et al*., 2023).

Growth Regulation

Growth retardants such as CCC (1000 ppm), B-nine (1500 ppm), and paclobutrazol (50–100 ppm) are effective in controlling plant height and improving flower quality under greenhouse and open conditions (Kumari *et al*., 2024). Gibberellic acid (GA_3) at 50 ppm promotes vegetative growth and early flowering in pot chrysanthemums.

Pest and Disease Management

Major pests include aphids (Macrosiphoniella sanborni), thrips, and leaf miners, controlled by alternate sprays of neem oil (2%), imidacloprid (0.3 ml/L), and spinosad (0.5 ml/L).

Common diseases are leaf spot (*Alternaria* spp.), powdery mildew (*Erysiphe cichoracearum*), and wilt (*Fusarium oxysporum*). Integrated disease management using *Trichoderma harzianum*, copper oxychloride (0.25%), and resistant cultivars has proven effective (Saini *et al*., 2022).

Harvesting and Post-harvest Handling

Flowers are harvested at fully open stage for local markets and tight bud stage for long-distance transport. Post-harvest treatments include pulsing with 8-HQC (200 ppm) + sucrose (2%) and storage at 2–4°C with 90–95% RH to prolong vase life (Kumar *et al*., 2023). Grading is based on stem length, flower diameter, color uniformity, and freshness. Flowers are bunched (5–10 stems) and packed in corrugated fiber boxes with polyethylene liners for export.

Yield and Economics

The average yield varies from 12–18 tons of flowers per hectare, depending on cultivar and management. Adoption of improved cultural practices, fertigation, and protected cultivation can enhance productivity by 25–30% over traditional systems (ICAR-DFR, 2024).

Breeding and Genetic Improvement

Selection and Hybridization

Traditional breeding in chrysanthemum began with mass selection and interspecific hybridization to enhance traits like flower size, color, and environmental adaptability. Hybridization between *C. indicum*, *C. morifolium*, *C. zawadskii*, and *C. nankingense* has produced most of the modern cultivars (Wu *et al*., 2023).

Controlled pollination is often labor-intensive due to protandry and self-incompatibility. Still, the approach remains essential for combining elite traits, such as early flowering and high petal count.

Mutation Breeding

Mutation induction using gamma rays, EMS (ethyl methanesulfonate), and X-rays has been effectively used to generate novel flower colors and forms. India, Japan, and Korea have developed numerous mutant varieties with desirable traits such as compact growth, semi-double flowers, and unique color tones (IAEA, 2023).

Example: The Indian variety 'Ratlam Selection' and 'Pusa Sona' were developed via mutation breeding (ICAR-DFR, 2024).

Modern Breeding Approaches

Polyploidy and Chromosome Manipulation

Polyploidy is a common evolutionary mechanism in chrysanthemum. Artificial polyploid induction using colchicine and oryzalin has been employed to produce cultivars with thicker petals, larger flowers, and delayed senescence (Rao & Bhat, 2022).

These polyploids often exhibit enhanced pigment concentration and increased vase life, making them ideal for cut-flower trade.

Molecular Marker-Assisted Breeding

Marker systems such as RAPD, SSR, AFLP, and SNP have facilitated the identification of genetic diversity and parentage in chrysanthemum germplasm. Recent studies using QTL mapping have identified loci associated with:

- Flower color (*CmCHS*, *CmF3H*, *CmDFR*)
- Flowering time (*CmFTL*, *CmSOC1*)
- Disease resistance (*CmWRKY*, *CmNBS-LRR*) (Liu *et al*., 2024; Patil *et al*., 2023).

Marker-assisted selection (MAS) now enables early screening for color intensity, compactness, and stress tolerance reducing breeding cycles significantly.

Biotechnological and Genomic Innovations

Somaclonal Variation and Micropropagation

Tissue culture techniques have revolutionized chrysanthemum improvement. Somaclonal variation during in vitro propagation generates new floral morphotypes, while micropropagation ensures the clonal fidelity of elite cultivars (ICAR-DFR, 2024). Embryogenic callus and somatic hybridization have also been explored to introduce resistance traits from wild relatives such as *C. nankingense*.

Genetic Engineering and Transgenic Chrysanthemums

Transgenic approaches have been applied to introduce genes for:

- **Color modification** (flavonoid and anthocyanin pathways)
- **Delay in flower senescence** (anti-ethylene genes)
- **Disease resistance** (*chitinase*, *glucanase*, *PR* proteins)
- **Abiotic stress tolerance** (*DREB*, *LEA* genes)

Japanese research groups successfully developed blue-flowered chrysanthemums via insertion of *delphinidin*-producing genes from *Petunia hybrida* (Noda *et al*., 2023).

Genome Editing and Omics Integration

The advent of CRISPR/Cas9 and RNA interference (RNAi) has brought precision breeding to the forefront. CRISPR-mediated knockouts of genes like *CmCCD4a* (carotenoid cleavage dioxygenase) have led to deeper petal coloration, while silencing of *CmFTL* regulates photoperiodic flowering (Liu *et al*., 2024). Integration of genomics, transcriptomics, proteomics, and metabolomics provides a holistic understanding of trait regulation enabling "next-generation chrysanthemum breeding."

Future Prospects

Future chrysanthemum breeding will rely heavily on:

- Speed breeding using controlled light and temperature regimes
- Digital phenotyping for rapid trait analysis
- Genome-wide association studies (GWAS) for trait mapping
- Bioinformatics and AI-driven selection tools Moreover, sustainable breeding programs integrating climate resilience and eco-friendly cultivars will ensure the continued dominance of chrysanthemum in global floriculture.

Future Scope

Future research on chrysanthemum should focus on developing climate-resilient and high-yielding varieties through molecular breeding, CRISPR/Cas9 gene editing, and *omics*-based approaches. Emphasis on eco-friendly production using biofertilizers, organic inputs, and integrated pest management can promote sustainable floriculture. Strengthening post-harvest handling, cold chain logistics, and value addition through essential oils, natural dyes, and herbal products will enhance its commercial scope. Moreover, the integration of digital tools, precision farming, and policy support can transform Guldaudi cultivation into a globally competitive and environmentally sustainable enterprise.

Conclusion

Chrysanthemum (*Chrysanthemum* × *morifolium* Ramat.), popularly known as Guldaudi, stands as the "Queen of Autumn Blooms" for its exceptional beauty, adaptability, and economic importance. It occupies a prominent place in global floriculture and Indian culture alike, valued for its rich varietal diversity, vibrant colors, and long shelf life. Advances in breeding, micropropagation, and molecular techniques have enhanced its productivity, stress tolerance, and post-harvest performance. Despite its potential, challenges such as varietal degeneration, pest and disease pressure, and inadequate post-harvest management persist. Strengthening propagation systems, adopting sustainable cultivation practices, and improving cold chain infrastructure are key to realizing the full commercial and ecological potential of Guldaudi. Thus, rediscovering and modernizing chrysanthemum cultivation can greatly contribute to sustainable floriculture and rural income generation.

Conflict of interest

The authors declare that they have no conflict of interest.

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