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Review Paper on Strategies for Off-Season Flower Production in Cut Flower Crops

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Authors' contributions

This work was carried out in collaboration between both authors. Author MK conceptualized the review, conducted the literature survey, and was primarily responsible for writing the manuscript. He also served as the corresponding author, overseeing all stages of the preparation and submission process. Author RB provided significant support in organizing the content, refining the structure of the manuscript, and performing thorough proofreading. Her critical feedback and suggestions greatly enhanced the overall quality and clarity of the paper. Both authors have read and approved the final manuscript.

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ABSTRACT

The aim of this review is to critically assess and interpret the recent advancements in flowering regulation techniques applied in the cut flower industry, which is increasingly driven by market-oriented and off-season demands. The scope of this paper encompasses key physiological, chemical, environmental and genetic approaches to manipulate flowering, including photoperiod manipulation, plant growth regulators (PGRs), temperature regulation (vernalization and thermal

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treatments), mechanical methods like pinching and pruning, staggered planting and genotype selection. These technologies enable growers to produce high-quality blooms irrespective of natural flowering seasons, thus ensuring year-round availability, enhanced market value and resource optimization. Advanced applications such as the use of precision agriculture tools, genotype-specific flowering scheduling and bulb forcing techniques have revolutionized the floriculture industry by improving predictability and consistency in flower production. Integration of cold storage for bulbs (e.g., tulips, lilies) with specific light treatments has proven effective in synchronizing flowering. Similarly, growth retardants and ethylene modulators are used to tailor floral traits as per market preferences. Mechanical methods contribute to increased flower uniformity and quality by influencing hormonal pathways and branching behaviour. While these advancements have significantly improved economic returns and production efficiency, challenges remain in the form of environmental concerns, overuse of chemicals and variability in cultivar responses. The review concludes that future strategies must emphasize sustainable technologies, including the integration of molecular breeding and eco-friendly inputs. This synthesis serves as a comprehensive reference for researchers, horticulturists, and commercial growers aiming to modernize cut flower production through advanced flowering regulation practices.

Keywords: Flower regulation; flower forcing; PGRs; photoperiod manipulation; cold storage; sustainable agriculture; cut flower industry and vernalization.

ABBREVIATIONS

PGR	*: Plant Growth Regulator*	*SD*	*: Short Day*
GA_3	*: Gibberellic Acid*	*LD*	*: Long Day*
ABA	*: Abscisic Acid*	*NI*	*: Night Interruption*
CCC	*: Chlormequat Chloride*	*EOD*	*: End-of-Day*
MH	*: Maleic Hydrazide*	*FR*	*: Far-Red Light*
R	*: Red Light*	*CFL*	*: Compact Fluorescent Lamp*
B	*: Blue Light*	*PPE*	*: Phytochrome Photoequilibrium*
W	*: White Light*	*UPOV*	*: International Union for the Protection of New Varieties of Plants*

1. INTRODUCTION

Flowers have always played an important role in our culture and society. Initially, people around the world cultivated flowers as a hobby solely for their aesthetic value, but with globalization and the free market economy, it has progressed to an industrial status. Cut flowers and pot plants are currently among the most commercially produced and exported ornamentals. The cut flower industry is gradually shifting away from traditional cultivation and towards extended cropping seasons and off-season production. In the cut flower industry, changing the flower time is highly desirable in order to achieve high-quality yield at specific times such as holidays and weddings. This is critical for balancing trade by reducing surplus produce entering the market. Making a plant to flower at a pre-determined time or under artificially imposed conditions with an aim to produce the flowers at desired period/ date is called flower regulation or flower forcing. Flower regulation is an operation performed or treatment given to the plant at appropriate stage to stimulate it to flower at a desired time (Sharma et al*.,* 2019). Growers who understand the concepts and techniques of flowering and flower regulation can plan their crop based on the season and trends that coincide with peak seasons such as Valentine's Day and Mother's Day and sell their product at destination markets. Flowering is the result of complex collaborative physiological, morphological, and biochemical processes. Understanding flower regulation can optimize harvest time, avoid spoilage due to overproduction at a specific time, reduce market glut, provide employment throughout the year and balances trade.

The primary objective of this review is to explore and summarize recent advancements in flower regulation techniques for the cut flower industry, with the aim of optimizing flowering time, enhancing quality, and ensuring year-round production. Flower regulation refers to the manipulation of physiological and environmental factors such as photoperiod, temperature, light quality, planting time, and plant growth regulators to control flowering behaviour in ornamental crops (Craig & Runkle, 2013; Palai et al., 2018; Sharma et al., 2019).

2. CURRENT SCENARIO OF FLOWER REGULATION IN INDIA AND THE WORLD

The global floriculture industry has seen significant expansion, with the cut flower trade alone valued at approximately USD 10.3 billion in 2023, a slight rise from USD 10.1 billion in 2022. The Netherlands continues to dominate global exports, contributing nearly 47% of the total value (USD 4.91 billion), followed by Colombia (USD 2.08 billion), Ecuador (USD 0.98 billion), Kenya (USD 0.66 billion), and Ethiopia (USD 0.23 billion). Major importing nations include the United States (USD 2.57 billion), Germany (USD 1.27 billion), and the Netherlands itself, which acts as a re-exporting hub (ITC Trade Map, 2024).

In India, floriculture is one of the fastest-growing sectors under horticulture. The total export of floriculture products stood at USD 86.6 million in 2023–24, with cut flowers contributing approximately USD 23.7 million. Key importers of Indian cut flowers include Malaysia (USD 1.7 million), Singapore (USD 1.58 million), the United Kingdom (USD 1.39 million), UAE (USD 1.26 million), and the Netherlands (USD 1.16 million) (APEDA, 2024). Despite the large area under floriculture cultivation estimated at over 330 thousand hectares, with a total production exceeding 3 million metric tonnes, cut flower productivity in India remains low compared to global standards (National Horticulture Board, 2023). The increasing demand for year-round flower availability and premium-quality blooms is driving the use of flower regulation techniques worldwide, including photoperiod manipulation, temperature control, and use of growth regulators. In India, regulated flower production is gaining attention to minimize imports, reduce wastage during surplus seasons, and stabilize market prices by matching flower availability with festive and export demands. Going forward, the integration of scientific flower regulation practices is expected to play a pivotal role in enhancing productivity, export potential, and income generation for Indian floriculturists.

This review emphasizes the significance of flower regulation techniques in the following aspects:

- Increasing flower yield and quality, thus enhancing profitability (Walters et al., 2019).
- Preventing overabundance of seasonal blooms that flood the market at low prices (Thao et al., 2018).
- Minimizing wastage and post-harvest losses of surplus flowers (Curry & Ervin, 2010).
- Lowering the incidence of pest and disease outbreaks prevalent during specific climatic windows (Amiri et al., 2018).
- Providing consistent employment opportunities across seasons (Janakiram et al., 2004).
- Improving farmers' income through high-demand, off-season sales (Baloch et al., 2011).
- Reducing cut flower imports during lean periods, thus balancing trade (Park et al., 2016).
- Meeting consumer demand for flowers during special events and festivals, regardless of natural blooming times (Yohei et al., 2012; Craig & Runkle, 2016).

3. TECHNIQUES OF FLOWER REGULATION

Flower regulation techniques are used in horticulture to synchronize blooming periods, improve flower quality, and meet market demands. These methods include practices such as pruning, pinching, and the application of plant growth regulators. Environmental controls like adjusting light exposure, temperature, and irrigation also play a vital role. Additionally, photoperiod manipulation and vernalization are used to influence flowering cycles in specific plant species. By carefully applying these techniques, growers can ensure consistent and predictable flower production throughout the year.

A. Photoperiodic manipulation

Photoperiodic manipulation is a method of regulating the growth and development of plants by controlling the duration of their exposure to light and dark periods. Plants have a natural internal clock that regulates their growth and development and this clock is influenced by the duration of light exposure they receive.

3.1 Classification of Plants Based on Photoperiod Requirement (Ha, 2014)

1. **Short-day plants (or long-night plants):** These plants start flowering when the night is longer than a certain number of hours. In other words, they need long periods of darkness to bloom. *Example: Chrysanthemum*
2. **Long-day plants:** These plants flower when they receive longer daylight than a specific minimum number of hours. So, they need short nights and long days to begin flowering. *Example: Carnation*
3. **Day-neutral plants (or indeterminate plants):** These plants are not affected by the length of day or night. They can flower regardless of how many hours of light or darkness they receive. *Example: Rose*
4. **Absolute long-day plants (qualitative long-day plants)** : The plants who's flowering absolutely depends on a long-day condition. They flower only under long-day conditions and never flower under unsuitable photoperiodic cycle conditions. Antonym is "facultative long-day plants".
5. **Facultative long-day plants (quantitative long-day plants):** The plants whose flowering is promoted by a long-day condition. They can flower even under inappropriate photoperiods, although flowering is delayed. E.g. Carnation
6. **Absolute short-day plants (qualitative short-day plants)** : The plants who's flowering absolutely depends on short-day conditions. They flower only under short-day conditions, and never flower under unsuitable photoperiodic cycle conditions. E.g. Chrysanthemum.
7. **Facultative short-day plants (quantitative short-day plants)** : The plants whose flowering is promoted by a short-day condition. They can flower even under inappropriate photoperiods, although flowering is delayed. Antonym is "absolute short-day plants".

To manipulate the photoperiod of flower crops, growers can use techniques such as artificial lighting i.e. by shading or covering the plants. Growers can use artificial lighting to providing supplementary light in case of long-day plants which can trick the plants into flowering earlier than they would naturally and they may use shading or covering to reduce the amount of light the plants receive for short day plants, which can delay flowering and extend the growing season for eg. chrysanthemum is a short-day plant and cannot normally form flower buds when the day length exceeds 14.5 hours (Sultanpuri, 2013). Photoperiod is the amount of time for which plants perceive light and dark periods in a 24-hour cycle (day length). It can also be defined as a plant's ability to use the length of day or night to change its behavior (Bradshaw and Holzapfel, 2017). Many developmental responses in plants, including flowering, can be controlled by photoperiod (Song and Shim, 2015). The leaves detect the photoperiodic signal and employ an internal time-keeping mechanism, the circadian clock, to 'measure time', predict and adapt to daily as well as seasonal changes. In most plants flowering time is determined by seasonal changes in the expression of the FLOWERING LOCUS T (FT) gene, which encodes signal molecule, a key component of florigen from leaves and shoots to induce flowering. Previous studies on Arabidopsis found that long-day conditions induce more FT expression and accelerate flowering compared to short-day conditions (Kobayashi et al. 1999). Flowering is encouraged in long-day (LD) plants when the period of darkness is less than a definite critical duration, whereas flowering is accelerated in short-day (SD) plants when the period of darkness is longer than a critical duration (Walters et al., 2019). Plants can also be day-neutral (DN), which means that their flowering is unaffected by photoperiod (Erwin and Runkle, 2007).

Photoperiodic responses in plants: Photoreceptors are the molecules used by plants to detect sunlight. Phytochrome is one of them that help plants to regulate developmental processes over their lifetime by sensitizing them to incident light. Plants are highly sensitive to red light (620 -700nm), far red light (700-800 nm) along with UV A (280-320 nm), UV B (320-380nm) light and blue light (380-500 nm). Phytochrome occurs in 2 forms that are interconvertible. P_R (Inactive) & P_{FR} (Active) form. P_R form absorbs red light (during the day) & changes into P_{FR}, while the P_{FR} absorbs far-red light (during night) & changes back to P_R. Unfiltered sunlight is rich in red light but deficient in FR light. In short day plant, P_R form causes flowering. In long day plant, P_{FR} form causes flowering.

During the summer, the days are long and the nights are short. Although sufficient conversion of P_R to P_{FR} occurs, the nights are short, leaving insufficient time for slow decay back to P_R. This causes P_{FR} accumulation, which leads to flowering in LD plants. However, this will prevent flowering in short-day plants. Because they require P_R form to flower. During the winter, the days are short and the nights are long. Thus, after converting P_R to P_{FR}, P_{FR} has enough night period to decay back to P_R, resulting in flowering in short day plants. However, flowering will be inhibited in LD plants because they require the P_{FR} form to flower.

Techniques to Manipulate Photoperiodism in Plants: - Photoperiodism—the plant's response to the length of day and night—can be effectively manipulated to either promote or inhibit flowering. Natural photoperiods can be artificially modified to simulate **short days (SD)** or **long days (LD)** based on crop requirements. This is particularly useful in commercial floriculture and controlled-environment agriculture.

Table 1. Classification of plants based on photoperiod requirements

Photoperiod Class	Examples of Plants	Critical Day Length	Flowering Season	Special Notes
Obligate Short-Day Plants	African Marigold, Mina Vine (*Ipomoea lobata*), Chrysanthemum, Poinsettia, Cocklebur	Light < Critical Length (e.g., 8 hrs light / 16 dark)	Late Summer to Early Winter	Flower only under strictly short-day conditions
Facultative Short-Day Plants	Cosmos, Globe Amaranth (*Gomphrena*), Moonflower (*Ipomoea*), Morning Glory, Signet Marigold (*Tagetes tenuifolia*), Zinnia, Creeping Zinnia (*Sanvitalia*), Celosia	Prefer short days, but can flower under long days too	Summer to Autumn	Enhanced flowering under short days
Obligate Long-Day Plants	Centaurea, China Aster, Fuchsia, Gazania, Lavatera, Lobelia, Monkey Flower (*Mimulus*), Petunia, Strawflower, Sweet Pea (*Lathyrus*), Primrose (*Oenothera*)	Light > Critical Length (e.g., 16 hrs light / 8 dark)	Spring to Early Summer	Require long days to flower
Facultative Long-Day Plants	Ageratum, Calendula, Dianthus, Linaria, Pansy (*Viola*), Petunia (Grandiflora), Salvia, Snapdragon, Statice, Sunflower, African Daisy (*Dimorphotheca*)	Flower more under long days	Spring to Summer	Can flower in short days, but better under long days
Day-Neutral Plants	Amaranthus, Cleome, Cobia, Stock, Verbascum, Wax Begonia (*Begonia × semperflorens*), Balsam (*Impatiens balsamina*), French Marigold (*Tagetes patula*), Rose, Gomphrena	No response to photoperiod	Any season (at maturity stage)	Flowering based on maturity rather than day length
Intermediate Plants	Coleus, *Echinacea purpurea*	Respond to a narrow range of photoperiods	Depends on conditions	Flower only within a specific range of day lengths
Short-Long Day Plants	Campanula	Require short days followed by long days	Sequential transition required	Dual photoperiod requirement
Long-Short Day Plants	Aloe	Require long days followed by short days	Sequential transition required	Dual photoperiod requirement

(Harshitha et al.*, 2021)*

Table 2. Research outcome of flower crop regulation

Year	Author(s)	Crop/Species	Photoperiod Technique	Treatment/Approach	Key Findings
2019	Sharma et al.	General (SD/LD plants)	Short Day (Blackout)	Black tarpaulin (5 PM–7 AM), <0.5 foot candles	Complete blackout with 150-gauge polythene effectively induces SD flowering.
2019	Walters et al.	Irisin, Alternanthera, Strobilanthus	Night Interruption	14h photoperiod using R:W:FR light	Flowering effectively inhibited by NI in LD-sensitive species.
2018	Thao et al.	Chrysanthemum	General (Lighting Source Comparison)	LEDs vs. CFLs	LEDs more effective for open field lighting in floriculture.
2018	Amiri et al.	Tulip	Light Spectrum Effect	W:R:B light vs. dark condition	W:R:B treatment gave maximum yield.
2018	Palai et al.	Chrysanthemum	Short Day	14h/16h dark periods	Shoot number and flowering varied with SD duration.
2016	Craig & Runkle	Multiple (LD) species	Intermediate PPE Photoperiods	PPE adjustments	Intermediate PPE more effective for flowering in LD species.
2016	Park et al.	Petunia	Light Quality Effect	Low R:FR ratio light	Promoted stem elongation and flowering.
2014	Islam et al.	Poinsettia	End-of-Day (EOD) Red Light	Reduced GA by 29% and IAA by 21%	Suppressed stem elongation through hormonal reduction.
2013	Craig & Runkle	Chrysanthemum, Dahlia, Tagetes	Night Interruption with LED	4h night light	Flowering delayed under NI treatment.
2013	Oh et al.; Runkle et al.	Campanula, Coreopsis, Cyclamen, Rudbeckia	Night Interruption / Day Extension	4h night or 6h day extension	Both equally effective in promoting flowering.
2012	Yohei et al.	Chrysanthemum	Night Break	Red-light pulse during night	Flowering inhibited by breaking the night.
2012	Sangma	Chrysanthemum	Controlled Short Day	HDPE, tarpaulin, satin (5 PM–9 AM)	HDPE advanced flowering by 30–35 days.
2011	Katrine & Carl	General	Irregular Night Breaks	Irregular light interruptions	Enhanced stem elongation and leaf area.
2011	Kjaer & Ottosen	Chrysanthemum	Night Break (Long Day)	Night breaks during SD	Improved photosynthetic area and saved energy.
2011	Verma et al.	General	Night Interruption (Long Day)	4h artificial night light	Increased vegetative growth and flowering via carb mobilization.
2011	Lee et al.	Paphiopedilum	Light Spectrum (LED)	Blue LED	Induced compact growth and more flowers.
2011	Baloch et al.	Marigold, Poppy, Phlox, Flax, Cornflower	Long Day	17h photoperiod	Flowering advanced by 22–25 days.
2010	Sipho & Paul	Not specified	Short Day (Blackout)	5 PM–9 AM covering	Flower yield and size significantly increased.
2010	Chung et al.	Oncidium	Light Quality	Blue, Red, FR LEDs	Enhanced morphology and biochemistry.
2010	Curry & Ervin	Kalanchoe	Photoperiod Sensitivity Test	9–15h photoperiods	No flowering at 15h; flowering declined with longer days.

Year	Author(s)	Crop/Species	Photoperiod Technique	Treatment/Approach	Key Findings
2008	Velmurugan & Vadivel	Chrysanthemum	Day Extension (Long Day)	2h extension after sunset	Max flower count and yield.
2006	Lopez & Runkle	Miltoniopsis orchid	SD + Vernalization	4–8 weeks SD followed by cold	>90% flowering success.
2005	Mattson & Erwin	General (SD plants)	Artificial Long Day	Maintain vegetative LD state	Useful for commercial stem production.
2004	Janakiram et al.	Chrysanthemum 'Ravikiran'	Short Day	10h dark / 14h light	Optimal vegetative and flowering traits.
2004	Clifford et al.	Poinsettia	Far-Red Filters	Compared with CCC treatments	Similar effect in height control.
2003	Mahant	Carnation	Night Lighting (Long Day)	4–6h incandescent light	6h light advanced flowering by 25 days.
1999	Runkle et al.	Rudbeckia fulgida 'Goldsturm'	Critical Photoperiod Analysis	≤13h for vegetative; ≥14h for flowering	Defined photoperiod thresholds.
1991	Sita Ram	Chrysanthemum (Aparajita, Ragini)	LD + SD + PGRs	LD via lights; SD via tarpaulin; CCC, MH applied	Regulated flowering Oct–Aug; PGRs influenced flower size & number.
1977	Vince-Prue	Fuchsia hybrida	EOD Red Light	Red light at end of day	Reduced internode length.
1966	Harris & Ashford	Carnation (var. White Sim)	Long Day (Extended Photoperiod)	Extended photoperiod	Promoted early flower initiation.
1960	White	Carnation	Long Day	>14h photoperiod	Promoted rapid growth and bud formation.
1943	Harder & Bode	Kalanchoe blossfeldiana	Night Interruption	Light 5–7h after dark onset	Most effective timing for flowering inhibition.

N- Night interruption, EOD*-End of day treatment, LD*-Long day, SD*-Short day, FR*- Far-red, R*-red, W*-White, B*-blue, CCC*- Cycocel, PPE*-photosynthetic photo efficacy, CFL*- Compact fluorescent light.*

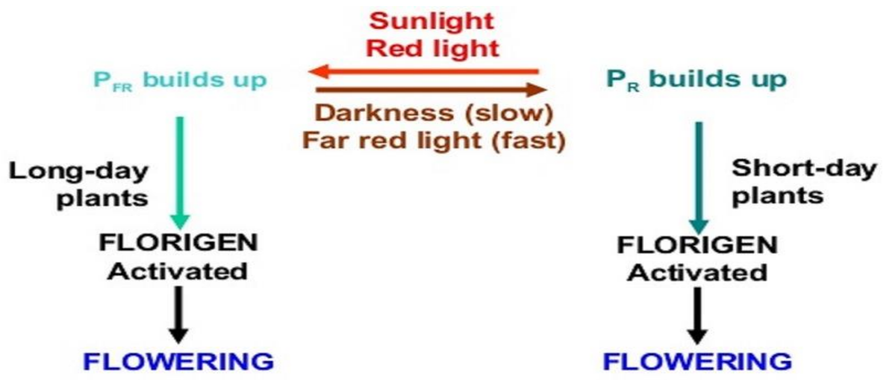

Fig. 1. Photoperiodic regulation of flowering via phytochrome conversion in long-day and short-day plants

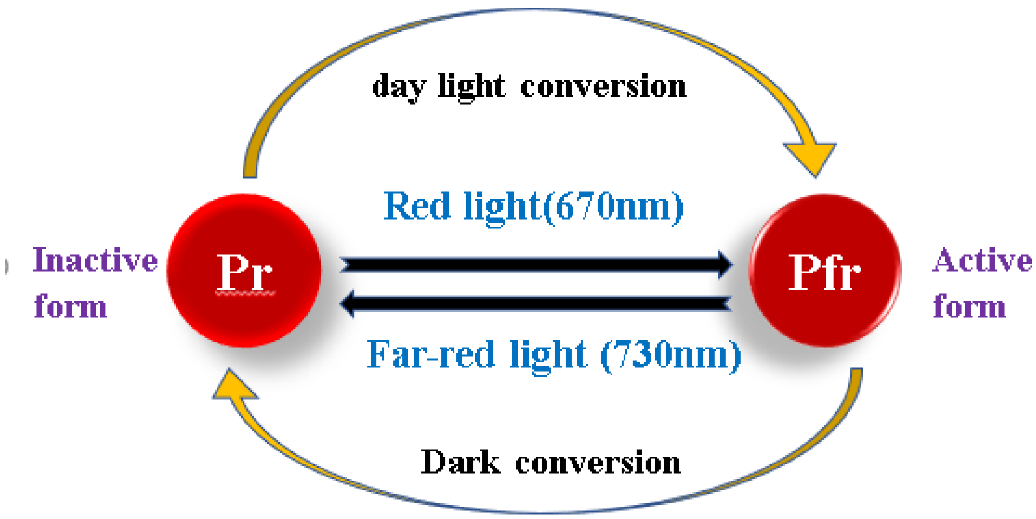

Fig. 2. Light-dependent interconversion of phytochrome forms Pr and Pfr. Red light (670 nm) converts Pr to Pfr (active), while far-red light (730 nm) or darkness converts it back

3.2 Photoperiod Regulation Techniques to Create Short Days

To induce short-day conditions, especially in short-day plants (or to delay flowering in long-day plants), artificial darkness is provided using blackout materials. Common methods include:

- **Blackout Tarp Method:** A black tarpaulin is suspended over plants using an iron frame from 5:00 PM to 7:00 AM, effectively creating a dark period exceeding 12 hours.
- **Material Used:** Dense black polythene sheeting with a thickness of 150 gauge is considered ideal, as it ensures near-complete light exclusion (below 0.5 foot-candles), which is critical to induce flowering in SD species.

Photoperiod Regulation Techniques to Create Long Days: - Under natural short-day conditions, long days can be artificially simulated to promote flowering in long-day plants through the following methods:

1. Day Extension

- Supplemental lighting is provided immediately after sunset.
- Common duration: 2–4 hours.
- Suitable for many LD plant species.

2. Night Interruption (Night Breaks)

- Artificial lighting is given in the middle of the night (e.g., 10 PM–2 AM).
- Duration: Continuous 4 hours.

- Most effective for inducing flowering in LD species by disrupting the long night.

3. Pre-dawn Lighting

- Lights are turned on from 2:00 AM until natural sunrise.
- Functions similarly to day extension by shortening the perceived night.

Among these, night interruption lighting for 4 continuous hours during midnight is the most effective and widely recommended for creating long-day conditions across diverse species.

Flower regulation by using plant growth regulators and retardants: Plant growth substance is important for overall performance, which includes growth, flowering and yield.

Growth regulators: Plant growth regulators (PGRs) and retardants are chemical compounds that can be used to regulate the growth and development of flower crops. They work by affecting the balance of hormones in the plant which can alter the timing and rate of growth as well as the quality and quantity of flowers produced. There are several types of PGRs and retardants that can be used in flower crop production, including:

Gibberellins: These are plant hormones that promote cell elongation and stem growth. They can be used to stimulate shoot growth and increase the size of flower buds. They contribute in cell elongation and cell division, breaks seed dormancy, stimulate flowering, increases height of plant, reduces the juvenile period required for flowering, Overcomes genetic limitations in various dwarf varieties. Early flower bud appearance with the application of GA_3 occurs due to the early production of florigen in GA_3 treated plants as GA_3 is a component of florigen which is mainly involved in flower initiation in the plant system.

Cytokinins: These are the plant hormones that promote cell division and differentiation. They can be used to increase the number of flower buds and promote branching. This hormone helps in promoting the cell's growth, development, differentiation, affecting apical dominance and delay in leaf senescence. of the roots. Cytokinin are usually formed in the in the meristem, rapidly dividing tissues such as root apices, growing shoot, etc.

Auxins: Auxins are plant hormones that promote cell elongation and growth. They can be used to stimulate root growth and promote uniformity in plant size. Natural plant sources provide indole-3-acetic acid and indole butyric acid, whereas synthetic sources provide naphthalene acetic acid and 2, 4-dichlorophenoxyacetic acid. These are produced by the apex of root and shoot and Facilitate flowering in plants.

Brassinosteroids: - Brassinosteroids (BRs) have been identified as the sixth plant hormone class. Brassinosteroids alter the mechanical properties of the cell wall during cell elongation. It enables cell expansion via turgor-driven methods.

Brassinosteroids perform the following functions in a plant:

- It works in conjunction with auxin for cell expansion and elongation.
- It also takes part in cell division and cell wall regeneration.
- It induces signal transduction that promotes vascular differentiation.
- It promotes pollen elongation, which is an important step for pollen tube formation.
- It counteracts abiotic and biotic stresses in plants.

Plant growth retardants: These are the compounds that are used to slow plant growth without altering developmental patterns or causing phytotoxicity.

Paclobutrazol: It is a synthetic PGR that inhibits gibberellin synthesis, leading to slow stem growth, smaller leaves and flowers. It can be used to promote compact growth and reduce plant height. It acts by inhibiting GA biosynthesis by preventing ent-kaurene oxidation. PBZ has been used to protect plants from a variety of abiotic stresses, including chilling, water deficit stress, flooding and salinity. PBZ inhibited vegetative growth components whereas GA stimulated vegetative growth components by increasing total shoot length and total bud number. Reduced growth in trunk and branch diameter has also been observed.

4. MALEIC HYDRAZIDE AND CHLORMEQUAT CHLORIDE

Maleic hydrazide is a synthetic growth regulator that inhibits cell division and elongation in plants, which leads to a reduction in plant height. It is commonly used to control the height of chrysanthemums, gladiolus and other flower crops. The application of maleic hydrazide can also improve flower quality by increasing the size, color and longevity of the blooms.

Chlormequat chloride is another synthetic growth regulator that is widely used in flower crop production to control plant height. It works by inhibiting the production of gibberellins, a class of plant hormones that promote stem elongation. It is commonly used in chrysanthemums, roses and other flower crops to improve plant structure, increase flower production and enhance flower quality.

Abscisic Acid: - Abscisic acid (ABA), discovered in the 1960s as a growth inhibitor, is a key plant hormone involved in various physiological processes. It is synthesized in several parts of the plant, including stems, leaves, fruits, and seeds. Abscisic acid primarily acts as an antagonist to gibberellic acid, modulating growth responses and maintaining homeostasis. Due to its crucial role in helping plants tolerate adverse conditions such as drought, salinity, and cold, it is often referred to as the "stress hormone" (Priyanka et al., 2018).

4.1 The Major Functions of Abscisic Acid Include

1. **Stomatal Regulation:** ABA stimulates the closing of stomata, reducing water loss during periods of water stress.
2. **Seed Maturation and Development:** It plays a vital role in the proper development and maturation of seeds.
3. **Inhibition of Growth:** ABA inhibits certain aspects of plant metabolism and delays seed germination under unfavourable conditions.
4. **Control of Abscission and Dormancy:** The hormone is involved in promoting leaf abscission and inducing dormancy in buds and seeds.
5. **Seed Dormancy and Stress Tolerance:** ABA induces seed dormancy, aiding the plant in surviving desiccation and inhibiting premature germination in adverse environments (Priyanka et al., 2018).

Ethylene: - Ethylene is a simple, gaseous plant growth regulator that is produced by the majority of plant organs, including ripening fruits and ageing tissues. It is an unsaturated hydrocarbon with double covalent bonds between carbon atoms. Ethylene is used as both a plant growth promoter and an inhibitor of plant growth. Ethylene is produced by ripening fruits and ageing tissues. Ethylene is the most widely used plant growth regulator as it helps in regulating many physiological processes. Facilitates senescence and abscission of both flowers and leaves.

The use of PGRs and retardants in flower crop production requires careful attention to the specific needs and characteristics of each plant species and cultivar as well as the goals of the grower. Overuse or improper application of PGRs and retardants can lead to negative effects on plant growth and flower production, so it is important to follow recommended rates and application methods. Additionally, the use of PGRs and retardants may be subject to regulations and restrictions, depending on the region and intended use.

Several studies have focused on the use of growth regulators and retardants to enhance the growth and flowering of different ornamental plants. Bindu Sharma (2002) examined the efficacy of growth retardants on *Lilium tigrinum*, finding that both preplanting dip treatments (Cycocel and Paclobutrazol) and spray treatments delayed bud formation. The application of Paclobutrazol (50 ppm) delayed bud formation by 24 days, indicating its effectiveness in regulating flowering. Priyanka et al. (2018) studied the effect of Benzyl Adenine (BA) and Gibberellic Acid (GA_3) on gladiolus. GA_3 at 150 ppm resulted in earlier flowering, while GA_3 at 250 ppm enhanced flower quality and prolonged flowering duration. Both GA_3 treatments improved flowering significantly compared to the control. Alpesh Kumar et al. (2018) investigated the impact of plant growth enhancers on tuberose 'Prajwal'. The application of enriched banana pseudo stem sap (15,000 ppm) led to earlier flowering and increased spike yield. The treatment also improved flower quality, highlighting the benefits of growth enhancers. Pawar et al. (2018) found that applying micronutrients combined with GA_3 (100 ppm) helped African marigold flower earlier, improving both flowering duration and flower yield. This combination proved beneficial for increasing the profitability of marigold cultivation. Dhanasekaran (2019) applied growth hormones (GA_3, NAA) and retardants (Cycocel, Maleic Hydrazide) to jasmine plants. GA_3 at 150 ppm advanced flowering by one month and enhanced flower yield and duration, suggesting its potential for improving jasmine production.

Mechanical Flower Forcing (physical method): Physical methods of flower regulation in crop plants involves manipulating the physical environment or structure of the plant to encourage or discourage flowering. Some common physical methods of flower regulation in flower crops include.

Pinching: Pinching is a common physical method of flower regulation in flower crops. Pinching can help in promoting more abundant and longer-lasting blooms in some plants. When you pinch off the growing tip of a stem or branch you remove the apical meristem which is responsible for producing auxins that suppress the growth of lateral buds. By removing the meristem, you release these lateral buds to grow and develop into new branches and more flowers, resulting in a more compact and bushier plant with more flowering points. The timing and frequency of pinching will depend on the specific plant and your desired results. Some plants may require pinching when they're young and actively growing, while others may benefit from pinching after they've started to flower. It's generally recommended to pinch back the plants when they are about one-third to half of their desired size to encourage fuller growth and more abundant flowering. It's important to note that over-pinching can also have negative effects on the plant, such as reducing the number of flowers and stunting growth. Therefore, it's important to be cautious and follow proper pinching techniques and timings for each plant species.

Pinching also influences other physiological processes in plants, such as the balance of growth hormones and the regulation of flower induction and development. For example, pinching can stimulate the production of cytokinins, a class of hormones that promote cell division and can enhance flower bud development. The specific physiological effects of pinching on flower regulation can vary depending on the plant species, timing, and frequency of pinching, as well as the environmental conditions in which the plant is grown. Baskaran and Abirami (2017): This study at CIARI, Port Blair, investigated the effect of pinching on African marigold yield. Three treatments were tested: no pinching, single pinching at 20 days after transplanting, and double pinching 15 days after the first pinching. Double pinching delayed flowering by 12 days but resulted in a longer flowering duration, higher quality blooms, and significantly increased flower and seed yield per plant, yielding three times more flowers than the control. Devi et al. (2019): Conducted at Navsari Agricultural University, this study examined the effect of pinching on four carnation varieties. The treatments included no pinch, single pinch, pinch and half, and double pinch. Double pinching delayed flowering by three months but produced the highest number of flowers per plant. The "pinch and half" treatment extended flowering duration the most. These results suggest that while double pinching delays flowering, it improves flower production and quality. Ehsanullah et al. (2021): This study at HRC, BARI, Gazipur, evaluated the impact of pinching schedules on chrysanthemum growth and quality. Treatments included no pinching, single pinching at 40, 50, or 60 days, double pinching at 40 and 50 days, and triple pinching at 40, 50, and 60 days. Triple pinching delayed flowering by three weeks but increased the number of branches and flower size. It also improved the number of flowers per plant, making it the most effective treatment for enhancing chrysanthemum yield and quality.

Pruning: - Pruning is a horticultural practice that involves selectively removing parts of a plant, such as branches, leaves or roots, to shape the plant, control its growth, promote better health and increase yield or quality of flowers, fruits or foliage. Pruning is commonly used to remove dead, damaged or diseased plant material, encourage new growth, manage plant size and shape and enhance plant productivity. The goal of pruning is to maintain the plant's form and improve its overall health and vigor. Pruning can be done manually with pruning shears, scissors, or saws, and the timing and extent of pruning may vary depending on the type of plant and the desired outcome.

Physiology of pruning: - Pruning in flower crops has a significant impact on the physiology of the plant, affecting its growth and development, as well as its ability to produce flowers. Here are some ways pruning affects the physiology of flower crops:

1. Promotes new growth: Pruning stimulates the production of new growth in the plant. When the tips of branches are removed, it signals the plant to produce new shoots, which can lead to more blooms and a bushier, more compact plant.
2. Increases flower production: By selectively removing buds or blooms, pruning can redirect the plant's resources towards producing larger, more robust flowers. This

is particularly true for species that produce multiple blooms on a single stem, such as roses or daisies.

3. Regulates hormone production: Pruning can affect the production and distribution of plant hormones such as auxins and cytokinin's which are involved in growth and development. By removing the tips of the branches or the flower buds, the plant may produce more auxins and direct its energy towards vegetative growth, delaying or promoting flowering.
4. Enhances light penetration: Pruning opens up the plant structure and increases light penetration to the lower branches, which can promote more growth and flower production throughout the plant.
5. Improves air circulation: Pruning removes dead or diseased branches, improving air circulation through the plant, reducing the risk of fungal or bacterial diseases and promoting overall plant health.
6. Water and nutrient uptake: Pruning can also affect the water and nutrient uptake by the plant. By reducing the number of flowers or buds, the plant's water and nutrient demands may decrease, which can affect its overall growth and development.

Lokhande et al. 2015 conducted a study at Satpuda Botanic Garden, Nagpur, analyzed the effect of pruning time and severity on *Jasminum sambac*. Pruning in the fourth week of January advanced flowering by a month, followed by pruning in the second week of January or at a height of 30 cm above ground, which advanced flowering by three weeks. Light pruning (45 cm above ground) advanced flowering by two weeks. Proper pruning timing and severity can be adjusted to meet flower demand effectively. Guleria 2016 Conducted at Dr. Y.S. Parmar University, this study examined the impact of pruning dates on *Rosa hybrida* cv. 'Super Star'. The earliest bud formation occurred with February 20 pruning, while October 21 pruning delayed it. Winter pruning, particularly in December, produced quality blooms from March to October. Pruning dates significantly affected flowering duration, with optimal timing ensuring extended bloom periods in mid-hill conditions of Himachal Pradesh. Overall, pruning is an essential practice in flower crop management that can help regulate growth, promote flowering and improve the overall health and productivity of the plant.

D. Cultural methods: Flower regulation in plants can be influenced by several factors, including the size of the propagule (the part of the plant used for propagation) and the depth at which it is planted. Plant propagules can include seeds, bulbs, rhizomes and stem cuttings. The size of the propagule can affect the timing and intensity of flowering in several ways. For example, larger propagules such as bulbs tend to have more stored nutrients and energy, which can promote earlier and more abundant flowering. Smaller propagules like seeds may need to establish a stronger root system before flowering, which can delay the onset of flowering. The depth at which a propagule is planted can also affect its flowering. Generally, planting deeper can delay flowering and reduce its intensity. This is because deeper planting may require the plant to allocate more energy to developing a stronger root system before it can produce flowers. On the other hand, planting shallower can promote earlier and more vigorous flowering, as the plant can allocate more energy to producing flowers and less to establishing roots. However, planting too shallow can also expose the propagule to environmental stressors like drying out, which can negatively impact flowering. It's important to note that the effects of propagule size and planting depth on flower regulation can vary depending on the specific plant species and environmental conditions. Therefore, it's always a good idea to research the specific requirements of the plant you're working with to ensure optimal flowering.

Physiology of flower regulation through different size of propagule and depth of planting: The physiology of flower regulation through different size of propagule and depth of planting can be understood by looking at the plant's response to these factors at the cellular and molecular level. Plant propagules, such as bulbs, contain stored nutrients and energy that can promote earlier and more abundant flowering. This is because the stored energy can be used to produce the reproductive structures, such as flowers, without requiring the plant to allocate resources to root development. In contrast, smaller propagules like seeds may need to establish a stronger root system before flowering, as the roots are necessary for the uptake of nutrients and water that are needed for flower production. The plant senses the availability of nutrients and water through a signalling pathway that involves various hormones, including gibberellins and auxins which promote root growth and development.

Once the roots are established, the plant can allocate resources towards flowering. The depth of planting can also affect flower regulation by influencing the plant's response to light and temperature. Plants require a certain amount of light and temperature to flower, and the depth of planting can affect the amount of light and temperature that reaches the plant's reproductive structures. Deeper planting can delay flowering and reduce its intensity, as the plant needs to allocate more resources towards root development before producing flowers. This is because deeper planting can result in less light and cooler temperatures, which can delay the onset of flowering. Shallower planting can promote earlier and more vigorous flowering, as the plant can allocate more resources towards flowering rather than root development. This is because shallower planting results in more light and warmer temperatures, which can promote flower development. Parmar (2009): Conducted at Dr. Y.S. Parmar University, this study assessed the impact of plant spacing and corm size on gladiolus hybrids. Larger corms (4.1-4.5 cm) planted at wider spacing (30x14 cm) resulted in earlier flowering by two weeks, longer flowering duration, and better overall performance compared to smaller corms (3.0-3.5 cm) at closer spacing (30x6 cm). Using larger corms and wider spacing enhanced flowering quality and duration, optimizing growth for gladiolus hybrids. Suhas (2015): This research at Dr. Y.S. Parmar University examined plant spacing and planting depth in tuberose cv. 'Double.' Spacing of 25x30 cm and planting depth of 2.0 cm led to faster flowering (125.86 days), while 25x15 cm spacing and 8.0 cm depth delayed flowering by 35 days (160.83 days). Wider spacing and deeper planting improved flower and bulb production, with optimal results for growth and flowering observed at 25x30 cm spacing and 2.0 cm depth.

E. Flower regulation through selection of different genotypes: planting of genotypes according to market demand and sequencing of early, mid and late flowering cultivars of a crop higher profit can be earned as a result of continuous marketable supply.

F. Temperature manipulation: Temperature is a critical factor for flowering. Temperature is especially effective in bulb flower initiation, especially when flower primordia form during storage after harvest in the summer but before replanting in the fall. Stored bulbs, such as tulips and irises, can be accelerated to flower by exposing them to low temperatures (9-11^{o}C), but a high temperature pretreatment (20 to 30^{o}C) is required if flower formation is to occur at all.

5. FLOWER REGULATION THROUGH CULTURAL METHODS

Flower regulation by Staggered planting: Staggered planting is a common technique used in flower crops to regulate flower production and extend the blooming period. This technique involves planting flowers at different times instead of all at once which can result in a more continuous and prolonged blooming season. One of the main benefits of staggered planting is that it helps to spread out the workload and resources need for planting and maintenance. Instead of having to plant and care for a large crop all at once, staggered planting allows farmers to focus on smaller batches of plants which can be more manageable and less resource-intensive. Another advantage of staggered planting is that it can help to minimize the risks associated with weather and other environmental factors. By planting at different times, farmers can reduce the chances of having their entire crop affected by a single event, such as a sudden frost or drought. Staggered planting can also help to regulate flower production and ensure a consistent supply of blooms throughout the growing season. By staggering the planting, farmers can control the timing of flower production and ensure that they have a steady stream of flowers to harvest and sell. Finally, staggered planting can help to improve the aesthetic appeal of flower crops. By spreading out the blooming period, farmers can create a more varied and visually interesting display of colors and textures, which can be particularly appealing to customers and visitors. Overall, staggered planting is a useful technique for regulating flower production in crops and it can offer a range of benefits for farmers and consumers.

Physiology of Staggered planting: The physiological basis for staggered planting in flower crops involves manipulating the timing and duration of several key plant developmental processes. These processes include the induction of flowering, flower development and senescence.

Induction of Flowering: In many flower crops, the induction of flowering is controlled by environmental factors such as photoperiod, temperature and light quality. By manipulating these environmental factors, farmers can control the timing of flowering and stagger the planting to extend the blooming period. For example, some plants require long days to induce flowering, while others require short days. By planting at different times, farmers can take advantage of these requirements and create a more continuous supply of flowers.

Flower Development: Once flowering has been induced, the plant enters a period of flower development, which involves the differentiation and maturation of floral organs. This process is regulated by a complex interplay of hormones, including auxins, cytokinins and gibberellins. By manipulating the timing of planting, farmers can control the duration of flower development and ensure a steady supply of blooms throughout the growing season.

Senescence: After the flowers have bloomed, they will eventually begin to senesce and die off. This process is also regulated by hormones, including ethylene which is responsible for many of the physiological and biochemical changes associated with senescence. By staggering the planting, farmers can prolong the duration of the blooming period and reduce the impact of senescence on the overall crop yield. In addition to these physiological factors, staggered planting can also have a significant impact on plant health and vigor. By planting at different times, farmers can reduce competition for resources such as water, nutrients and light which can help to promote healthier and more robust plants. This can result in higher quality flowers and a more productive crop overall. Kaushal (2013) conducted a study at Dr. Y S Parmar University, Himachal Pradesh, to assess the effect of seven different transplanting dates (6th April to 5th June, 2012) on the growth and flowering of China Aster varieties—Kamini, Shashank, and Violet Cushion. Early planting (6th April) resulted in delayed flowering but gave the highest flower yield (158.1 stems/plot) and longest flowering duration (62.4 days). Late planting (5th June) led to earlier flowering but reduced flower yield (121.7 stems/plot) and duration (41 days). Among varieties, Kamini consistently showed better performance in yield. Staggered planting every ten days from April to June is recommended for continuous flower production from August to mid-November. Khutiya (2016) studied the effect of twelve staggered planting dates (from 13th February to 28th July 2015) on Gladiolus cv. 'Solan Mangla' at Dr. Y S Parmar University, Nauni, Solan. Results showed that early planting (13th Feb–14th May) produced longer spike lengths (up to 95.99 cm), more florets per spike (up to 15.06), and longer flowering durations, making this window optimal for marketable flower production from June to August. Sultanpuri (2018) explored staggered monthly planting of three carnation cultivars ('Dumas', 'Kiro', and 'Master') from October 2014 to April 2015. All planting dates yielded satisfactory flower quality and quantity, with mid-February to mid-April plantings giving slightly better flowering durations and cut stem yields (up to 194.09 stems/m^2 in April). Sangmesh (2021) examined staggered planting of marigold cvs. ‘Pusa Narangi Gainda’ and ‘Pusa Basanti Gainda’ under open and naturally ventilated polyhouse conditions. Plantings from 10th July to 25th August provided continuous flowering from September to February, with highest yields under polyhouse conditions (up to 730.43 g/plant). Basoli (2009) analysed nine staggered planting dates (from 9th April to 7th August) for eight chrysanthemum cultivars. Early planting dates (April–May) led to earlier flowering (from September to October) and longer flowering durations, whereas late plantings (July–August) delayed flowering to late October and November. Staggered planting at 15-day or monthly intervals was consistently recommended across all crops for sustained flower availability and optimal yield.

6. FLOWER REGULATION THROUGH SELECTION OF DIFFERENT CULTIVARS/ GENOTYPES

Flower regulation in flower crops can be achieved through the selection of different cultivars or genotypes with specific characteristics related to flowering. Here are some ways in which cultivar or genotype selection can be used to regulate flower growth:

Early or late flowering: Flower crops can be selected for early or late flowering, depending on the desired timing of harvest. For example, some cultivars of chrysanthemums are early flowering, while others are late flowering, allowing growers to extend the harvest season and staggered production.

Uniformity of flowering: Cultivars that exhibit uniform flowering can be selected to ensure that all plants in a crop reach the flowering stage at the same time. This is important for crops that are sold as cut flowers or for those that require uniformity for aesthetic purposes.

Compact growth habit: Cultivars with a compact growth habit can be selected to regulate plant height and prevent excessive stem elongation. This is important for crops that are sold as potted plants, such as African violets where a compact growth habit is desirable.

The selection of different cultivars or genotypes can play an important role in regulating flower growth and development. By choosing cultivars with specific characteristics related to flowering, growers can tailor their crops to meet market demands and optimize yields.

Response group: -It refers to the number of weeks taken to flowering from the starting of short days. The response group classification will help the correct choice of varieties for round the year flowering. Each chrysanthemum variety has its specific photo induction requirement that is the number of lights and continuous long dark periods (short days) required by its plant for coming into bloom after it has attained maturity. Varieties require differential photoperiod ranging from 8 to 15 weeks for coming into bloom. A variety requiring 8 weeks for photo induction period is said to belong to 8 weeks response group. In chrysanthemum cultivation, response groups are classifications of cultivars based on their photoperiodic response or how they respond to changes in day length. The response groups are determined by the timing of flower bud initiation and the number of hours of darkness required to initiate flowering. There are three main response groups for chrysanthemums:

The physiology of flower regulation through the selection of different cultivars or genotypes in flower crops is based on the genetic makeup of the plant. It's complex and multifaceted, involving a complex interplay of genetic and environmental factors as well as hormonal regulation. The timing of flowering and other characteristics related to flower development are controlled by a complex interaction of genetic and environmental factors. Different cultivars or genotypes of flower crops may have different genes or gene combinations that control the timing and duration of flowering, as well as other traits related to flower development, such as flower color, size and shape. For example, some cultivars of chrysanthemums are bred to flower early, while others are bred to flower late, based on the presence or absence of specific genes or gene combinations. Different cultivars or genotypes may have different hormone profiles or responses to hormones, which can affect the timing and duration of flowering, as well as other traits related to flower development. Flowering time is a critical trait in floriculture crops as it directly influences market availability, scheduling, and profitability. Various studies have been conducted under the specific Agro-climatic conditions of Nauni, Solan, to evaluate the flowering behaviour of ornamental crops. Usha (2010) categorized newly evolved Chrysanthemum selections into different response groups based on the number of weeks taken to flower under controlled photoperiod, highlighting the potential for staggered planting to ensure year-round flower availability. Similarly, Garg (2019) evaluated Alstroemeria genotypes by dividing them into early (≤140 days), mid (140–160 days), and late (>160 days) flowering categories, enabling selection based on production timelines. Sangeeta (2019) applied UPOV guidelines to Lilium and classified genotypes from very early to very late bloomers (ranging from <50 to >125 days), offering detailed insights for varietal differentiation. Hiremath (2020) studied Gladiolus under DUS parameters, grouping 84 Indian and exotic varieties based on days to flowering, which further assists in identifying suitable varieties for early, mid, or late-season markets. Lastly, Preeti Sharma (2014) evaluated French Marigold genotypes under PPVFRA norms and classified them by flowering time, revealing hybrids like ms4 × Harmony Boy and ms10 × Spray Boy as ideal for mid-season blooming. Together, these studies underline the strategic advantage of selecting genotypes with varied flowering periods to achieve continuous production and maximize returns in floriculture.

Flower regulation by temperature regulation: Temperature regulation is a common method for flower regulation in flower crops. The timing of flowering in many flower crops is influenced by temperature, as well as other environmental factors such as photoperiod and light intensity. In general, temperature influences flower development by affecting the rate of plant growth and the timing of developmental stages. One common method for temperature regulation is to use temperature-controlled greenhouses or growth chambers to maintain a consistent temperature range. This can help growers to achieve optimal temperatures for flower development throughout the growing season, regardless of external weather conditions. Another temperature regulation method is to use shading or cooling systems to prevent overheating during periods of high temperature. Overheating can cause flower buds to abort or produce deformed flowers. Shading or cooling systems can be used to reduce temperatures during the day or during periods of high light intensity. In some cases, temperature manipulation can also be used to induce or synchronize flower development. For example, in tulips a cold treatment (vernalization) is required to induce flower bud formation. By exposing the bulbs to a specific temperature range (usually 4-10°C) for several weeks, growers can synchronize flower development and induce flower bud formation. In conclusion, temperature regulation is a common method for flower regulation in flower crops. By controlling temperature, growers can manipulate the timing of flower development and improve the quality and quantity of flowers produced. Temperature regulation can be achieved through various methods such as temperature-controlled greenhouses or growth chambers, shading or cooling systems and vernalization.

7. BULB FORCING

Bulb forcing is a technique used to induce bulbs of certain flower crops to bloom outside their natural season, often for commercial or ornamental purposes. The technique involves mimicking the cold and dark conditions that the bulbs would experience during winter in their natural habitat, which triggers them to start growing and flowering. The process of bulb forcing involves the following steps:

Selection of bulbs: High-quality bulbs with a certain size, age and physiological condition are selected for forcing. Typically, bulbs that are used for forcing should be large and healthy, with no signs of damage or disease.

Pre-chilling: Bulbs are placed in a cool, dark environment (e.g., a refrigerator) for several weeks to simulate the cold winter conditions they would experience in their natural habitat. This chilling period typically ranges from a few weeks to a few months, depending on the species and cultivar.

Planting: Once the bulbs have been chilled, they are planted in a suitable growing medium such as soil, sand or peat moss. The bulbs are planted at a depth of two to three times their height and the growing medium is kept moist.

Growing conditions: The planted bulbs are kept in a cool and dark environment for a few weeks until they start producing shoots. Then the temperature and light conditions are gradually increased to encourage the growth and development of the plant.

Flowering: Depending on the species and cultivar, the bulbs will bloom within a few weeks to a few months after planting. Once the flowers have bloomed, the plant can be moved to a more suitable location for display or sale.

Some common flower crops that are forced from bulbs include tulips, daffodils, hyacinths and lilies. Bulb forcing is commonly used for ornamental purposes, such as for cut flowers, potted plants and landscape displays. It allows growers to produce these flowers outside of their natural growing season which can be beneficial for meeting market demands and extending the availability of these flowers to consumers.

Thermoperiodic response of bulbous plants: Thermoperiodism is process in those bulbous ornamentals which only flower after receiving a recurring period of warm and cool temperatures.

Warm-Cold-Warm sequence: Bulbs that show their active vegetative and flowering in spring generally exhibit their rest period in summer, when temperatures are high and the soil is dry. They resume their further growth in the autumn. This group of bulbs requires a warm-cold-warm cyclic period to express active growth and complete their life cycle. Examples: Tulipa, Daffodils, Hyacinth, Freesia etc. (Khodorova et. al, 2010).

7.1 Phases of Bulb Forcing

The entire bulb forcing Programme has been broken down into the four steps listed below:

Production phase: The term "production phase" refers to all processes necessary to produce marketable bulbs. The bulb production phase is further broken down into the following steps:

1. Harvesting of bulbs, grading of bulbs into planting bulbs and marketable bulbs and storage
2. Planting, establishing roots and low temperature treatment for flowering;
3. Development of leaves and flower stalks;
4. Flowering
5. Enlargement of bulb size and increase in quantity.

The programming phase: This phase includes all procedures from bulb harvesting to placing bulbs under greenhouse conditions. This phase includes bulb harvesting, pre-planting storage for flower primordia initiation and roots in cool, moist conditions.

Greenhouse phase: Many environmental factors including temperatures, humidity, carbon dioxide, photoperiod length, light intensity, fertilizer, suitable ventilation, hygiene and insect control are managed throughout this phase. In the greenhouse where flower stalk lengthening occurs, bulbs are planted during this time.

Marketing phase: - The marketing phase is a crucial stage in the commercial production of Lilium, where plants continue to develop until they reach a market-ready condition. According to Imanishi et al. (2002), growers or forcers must begin with a clear understanding of the marketing phase and manage the entire crop from the production phase with the market demands in mind. This forward-planning ensures timely and quality delivery of the final product, especially when targeting specific events such as Easter.

To meet the market schedule for Easter lilies, special pre-cooling techniques are applied to Lilium bulbs. The classification of Easter dates early (e.g., March 26, April 1), medium (e.g., April 7, April 13), and late (e.g., April 18, April 22) plays a critical role in determining bulb treatment schedules. The timing of bulb arrival in relation to the Easter date influences the handling protocols. For consistent and synchronized flowering, bulbs are subjected to vernalization at a temperature of 4 to 4.5°C for approximately six weeks. This process, referred to as *cooling before potting*, ensures uniform sprouting and flowering at the desired time.

The production phase encompasses all cultural practices necessary to produce a commercial-quality Lilium bulb. The primary method of propagation is through scales or "bulblets," and it typically takes about two years to develop a bulb to a marketable size. Harvesting of these bulbs generally occurs between September and October. In North America and California, the most sought-after Easter lily cultivars include *Nellie White* and *Ace Lily*, which are specifically cultivated to meet the seasonal demand during the Easter period.

Programming Phase:

- Easter lily bulbs are cooled at 4.5°C for 6 weeks, moisture content in peat moss used for storage should be 30 to 50 % (this will retain existing basal roots of the bulbs).
- 6 weeks of cold treatment results in rapid shoot emergence and subsequent rapid and uniform flowering.

Greenhouse phase:

Greenhouse forcing temperatures:

- Day temperature: 21°C.
- Night temperature: 15° to 17° C.

There are 3 growing stages in lily

1. Planting to flower initiation
2. From flower initiation to time when floral buds become visible in the foliage.
3. From bud visible stage to until the first floral bud opens (30 to 35 days).

Floral initiation: when the apical meristem of lily ceases producing leaves (Vegetative stage of growth) and begins forming floral buds (reproductive stage of growth). Normally plants are 10 to 15cm tall when they become reproductive.

Leaf counting method: -

- Leaf number is fixed at stage one. In stage 2 leaves unfold and terminate to form visible buds. At this stage leaf unfolding rate can be controlled to regulate flowering.
- Leaf Unfolding rate = number of leaves yet to unfold/ desired date of blooming.

Table 3. Effect of daily average temperature on leaf unfolding rate

Average Daily Temp (°F)	**53**	**55**	**57**	**59**	**61**	**63**	**65**	**67**	**69**	**70**	**72**	**74**	**76**	**78**	**80**	**82**
Leaves Unfolded/ Day	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5

Forcing Tulip: Tulip bulbs are picked in the late summer and stored for a week at 34^0C in order to flower early in the season. They are then heated to 17^0-20^0C to hasten the commencement of floral development and organogenesis. The bulbs are regularly pre-cooled at 7–9°C for six weeks before planting once the floral bud has reached trilobed gynoecium stage. Both the roots and the continued development of the floral components are improved by this treatment. The bulbs are rooted at lower temperatures after planting at 9°C. The bulbs are subjected to a 15-week cumulative cold temperature treatment before being placed in a greenhouse heated to 18°C. Plants can be stretched out in the dark until the lowest internode is visible for early forcing. The main purpose of midseason forcing is to obtain flowers for Valentine's Day. In order to grow the floral portions, bulbs are taken during the early rainy season and stored at 17^0-20^0C. The following week, bulbs are precooled at 9^0C. While potted tulips have a 14–16-week cold therapy, cut tulips receive a 16–20-week cold treatment. Then they are placed 17^0C in the greenhouse. For Easter, the late forcing is done. Bulb harvesting takes place during the rainy season, and bulbs are stored at 23°C for one month and 20°C for another. After planting, the low temperature treatment (5^0C) demonstrated reasonable shoot growth and strong flowering over a longer period of time (12–14 weeks). The influence of cold storage duration and plant growth regulators (PGRs) on the growth and flowering of ornamental bulb crops has been widely studied. Dhiman (1997) explored the effects of cold storage and PGR treatments on Lilium hybrids, particularly the cultivars Gran Paradiso and Pollyana. The study found that bulbs stored for 12 weeks at 20°C sprouted and flowered significantly earlier than untreated bulbs, with Pollyana demonstrating superior flower production and quality. Additionally, 8 weeks of cold storage was optimal for achieving the highest number of blooms and prolonging flowering duration. Similarly, Moe Wickstrom's (1973) research on tulips revealed that cold storage at 50°C for 12 weeks advanced flowering by 54 days for Paul Richter and 45 days for Apeldoorn, compared to shorter storage durations. These studies underscore the critical role of cold storage in regulating flowering time, improving flower yield, and enhancing quality in bulb crops, offering valuable insights for growers aiming to optimize their production schedules and meet market demands. Both studies demonstrate that combining cold storage with PGR treatments can significantly enhance flower growth, quality, and marketability in cut flowers.

8. MERIT AND DEMERIT OF FLOWER REGULATION

8.1 Merits of Flower Regulation in Flower Crops

- **Increased yield:** Flower regulation can increase flower yield by ensuring optimal timing of flowering and increasing the number of flowers produced per plant.
- **Consistent quality:** Flower regulation can help ensure consistent flower quality by promoting uniform flower size, color and shape.
- **Marketability:** Flower regulation can help ensure that flowers are available for sale during peak demand periods, which can improve marketability and profitability.
- **Resource optimization:** Flower regulation can help optimize resources such as water, nutrients and labor by ensuring that flowers are produced at the most efficient time.
- **Improved pest and disease control:** Flower regulation can reduce pest and disease problems by promoting optimal plant growth and reducing the incidence of stress-related problems.

8.2 Demerits of Flower Regulation in Flower Crops

- **Environmental impact**: Chemicals used as plant growth regulators or retardants for flower regulation can leave residues on flowers, which can pose health risks to consumers and impact the environment.
- **Reduced plant vigor:** Flower regulation can reduce plant vigor by suppressing natural growth processes, which can impact the overall health of the plant.
- **Increased production costs**: The use of flower regulation techniques can increase production costs due to the need for specialized equipment and materials.
- **Limited consumer acceptance:** Some consumers may be hesitant to purchase flowers that have been artificially regulated, preferring instead to buy flowers that have been grown naturally.

8.3 Future Thrust of Flower Regulation in Flower Crops

Flower regulation in flower crops is an important aspect of plant growth and development that impacts flower quality, quantity and timing of flowering. The future thrust of flower regulation in flower crops will likely focus on several key areas including:

Development of new flower regulation technologies: There is a need for the development of new flower regulation technologies that are more effective, safe and environmentally friendly. These could include novel approaches such as gene editing, RNA interference or other biotechnologies.

Integration of flower regulation with other crop management practices: Flower regulation needs to be integrated with other crop management practices, such as irrigation, fertilization, and pest control to ensure optimal plant growth and flower production.

Use of precision agriculture techniques: Precision agriculture techniques such as sensor technology, drone imaging and artificial intelligence can be used to monitor plant growth and flower development and provide targeted flower regulation treatments.

Optimization of flower regulation treatments: There is a need to optimize flower regulation treatments to achieve the desired outcomes while minimizing negative effects on plant growth and development. This could involve a better understanding of the molecular mechanisms underlying flower regulation and the development of new formulations and application methods for flower regulation chemicals.

Sustainable flower regulation practices: There is increasing demand for sustainable flower production practices that minimize environmental impact and reduce the use of synthetic chemicals. Future thrust in flower regulation in flower crops will also focus on developing sustainable flower regulation practices.

Overall, the future thrust of flower regulation in flower crops will focus on developing more effective, safe and environmentally friendly approaches to achieve optimal flower quality, quantity and timing of flowering while promoting sustainable production practices.

9. CONCLUSION

Floriculture is a major income-generating sector, but seasonal overproduction often leads to low prices and wastage, while off-season demand sees price spikes. Regulating flowering through techniques like photoperiod manipulation, temperature control, planting time adjustment, and pinching can align production with market needs. These methods enhance yield, quality, and profitability while reducing losses. However, they should be applied judiciously, considering cost, environmental impact, and consumer preferences. When integrated with good crop management, flower regulation is a valuable strategy for year-round, market-driven flower production.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models (e.g., ChatGPT) have been used during the writing or editing of this manuscript only for grammar correction and sentence restructuring purposes. No conceptual, analytical, or content-level changes have been made using AI.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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