

Insights into Flowering Dynamics in Chilli (*Capsicum annuum* L.)

Nisha S. Patil¹, Angad Devkar², Muthyam Bhargavi³, Sonali Bhagat⁴ and
*Yogesh Shaniware⁵

¹PG Scholar, Agricultural Economics Section, RCSM College of Agriculture, Kolhapur, Mahatma Phule Krishi Vidyapeeth, Rahuri-413722, Maharashtra, India

²M.Sc. Agriculture (Genetics and Plant Breeding), Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India

³M.Sc. Scholar, Department of Agronomy, Renaissance University, Indore, Madhya Pradesh, India

⁴Assistant professor, Department of Microbiology, SAU.VDCFT, Amravati, Maharashtra, India

⁵Ph.D. Scholar, Department of Genetics and Plant Breeding, University of Horticultural Sciences, Bagalkot-587104, Karnataka, India

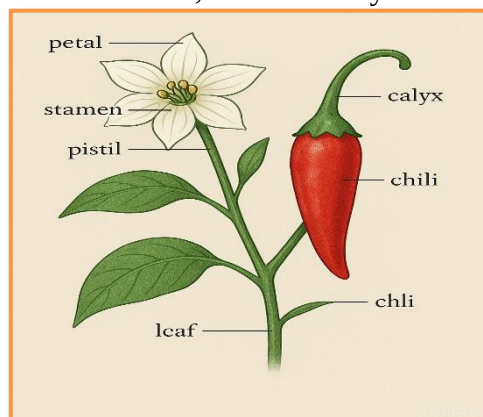
*Corresponding Author's email: yogeshshaniware1@gmail.com

Chilli (*Capsicum annuum* L.) is valued for its flavour, colour, pungency and nutritional qualities, is one of the most important vegetable and spice crops farmed worldwide. Chilli, both in ripe and green stage is an important condiment of India. Chilli is a member of the Solanaceae family, have a very varied floral biology that has a direct impact on fruit set, yield and the development of hybrid seeds. Hormonal, environmental and genetic factors regulate the complex physiological process of chilli flowering. The reproductive efficiency of the chilli is often influenced as the crop frequently experiences issues like flower drop, poor fruit set and variability in anthesis timing, which lower productivity, flowering behaviour in most of the Indian conditions. While endogenous growth regulators like auxins, gibberellins and cytokinins affect floral differentiation and fruit set, photoperiod and temperature are important factors in controlling floral initiation and anthesis. Therefore, it is crucial to study the mechanisms behind flowering behaviour in order to improve crops, produce hybrid seeds and create plans to increase fruit set and yield stability. This article focuses on the complete insights of chilli's flowering pattern and mechanisms along with the floral biology, anthesis and factors influencing the flowering behaviour in chilli across the Indian conditions.

Introduction

In many nations across the world, chilli (*Capsicum annuum* L.) is a significant cash crop and spice. It is known that South and Central America is where capsicum spp. originated. Its primary centre of origin is Mexico, where it was first domesticated; its secondary centre of origin is Guatemala. The five most commonly cultivated species of Chilli peppers are *Capsicum annuum*, *Capsicum frutescens*, *Capsicum chinense*, *Capsicum baccatum* and *Capsicum pubescens*. Each chilli pepper species has various characteristics such as flavour, heat intensity, and appearance (Bosland *et al.*, 2012).

Using hybrid crops, expanding the area under crop cultivation and implementing better agro-techniques could all help meet the growing demand for vegetables. In India, chilli has substantial



economic value. With a 39.78% global production share, India is the world's largest producer of dried chillies. The nation grows 3.26 million metric tonnes of chilli a year on 739000 hectares. In 2023–2024, India produced 1.98 million metric tonnes of chillies, making it the world's leading producer. The biggest producer of chillies in India is Andhra Pradesh, which is followed by Telangana, Madhya Pradesh, Karnataka and Odisha (Statista, 2023). The most widely grown Indian chilli varieties are Bhut Jolokia, Kashmiri, Guntur, Jwala, Kantari, Byadagi, Bhiwapur, Nandurbar, Ramnad, Dhani, Tomoto, Madras Puri, Kholā and Dalle Khursani. India has emerged today as the foremost producer and exporter of chilli contributing to almost one fourth of world production. After tomatoes, chillies are the second most important solanaceous vegetable.

The initiation, development and regulation of flowering in chilli are complex processes influenced by genetic, physiological and environmental factors (Singh, 2001). Being a day-neutral plant, chilli is capable of flowering under a wide range of photoperiods, though temperature, light intensity, nutrient availability and hormonal balance profoundly affect the timing and intensity of floral initiation. The flower initiation in chilli usually occurs 30 to 45 days after transplanting, depending on cultivar and growing conditions (Reddy *et al.*, 2014). Environmental stress, nutrient imbalance, or hormonal deficiency at this stage can lead to delayed flowering, flower drop, or poor fruit set. Nutritional and hormonal regulation also plays a vital role in flowering. In following sub-points the detailed insights of flowering behaviour in chilli is discussed:

- **Flower morphology:** The flower of chilli is complete, bisexual, actinomorphic and typically pentamerous, meaning the floral parts are arranged in multiples of five. The flowers are solitary or in small clusters, borne on slender pedicels in the axils of leaves. They exhibit hypogynous arrangement, with the ovary superior and all other floral parts inserted below it.

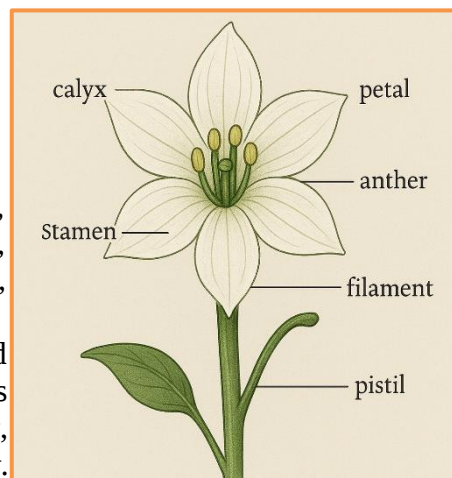
Calyx: It consists of five green sepals that are united at the base, forming a persistent cup-like structure that remains attached even after fruit development. The sepals are small, green and herbaceous, providing protection to the flower bud during its early stages.

Corolla: It comprises five white or pale green petals, which are fused slightly at the base forming a shallow, star-shaped flower when open. The petals are delicate, membranous and actinomorphic (radially symmetrical).

Androecium: It consists of five stamens, each attached to the corolla tube by short filaments. The stamens alternate with the petals. The anthers are yellow, ditheous and introrse, releasing pollen longitudinally. The filaments are slender and greenish-white.

Gynoecium: The gynoecium is syncarpous, composed of two or more fused carpels forming a bilocular or multilocular ovary, depending on the species and cultivar. The ovary is superior, smooth and conical, containing numerous ovules attached to axile placentation. The style is slender and elongate, terminating in a capitate stigma, which is slightly lobed and receptive at the time of anthesis.

- **Anthesis in chilli:** Anthesis refers to the process of flower opening and the period during which a flower is fully expanded and functionally active for pollination and fertilization. It is a critical reproductive event determining the success of pollination, fertilization and subsequent fruit set. In most chilli cultivars, anthesis generally occurs in the early morning hours, typically between 6:00 AM to 10:00 AM, depending on environmental conditions (Reddy *et al.*, 2023). Flower buds usually start enlarging a day before



opening and the corolla lobes begin to unfold slightly before sunrise. Full anthesis is generally completed by mid-morning when the corolla is fully reflexed and the reproductive structures are exposed. Under high temperature or low humidity conditions, the process of anthesis tends to accelerate, while under cooler and humid conditions, delayed or prolonged anthesis may be observed. Each chilli flower remains fully open and functional for one to two days, depending on environmental conditions. Anther dehiscence generally coincides with or occurs slightly after anthesis. The anthers dehisce longitudinally, releasing dry, powdery pollen grains. The stigma becomes receptive a few hours before anthesis and remains receptive for about 24 to 48 hours after flower opening. The optimum temperature range for anthesis in chilli is 25 to 30°C. High temperatures (>35°C) or low relative humidity (<40%) may lead to poor pollen viability, reduced stigma receptivity and flower drop.

- **Pollen morphology:** The pollen grains of chilli are typically yellow, smooth, small to medium-sized, spherical or sub-spherical and tricolpate (having three germinal furrows or apertures). The exine (outer wall) is thick, sculptured and covered with minute spines or granules, which help in adhesion to the stigma. The intine (inner wall) is thin and uniform. Pollen diameter usually ranges between 25 to 45 µm, depending on the cultivar and environmental conditions during development. Pollen viability in chilli is generally high at the time of anthesis but declines rapidly within a few hours. The highest viability (80–90%) is usually observed at anthesis or shortly after anther dehiscence, after which it progressively decreases due to desiccation and temperature stress.
- **Pollen germination:** Pollen germination in chilli occurs when viable pollen grains land on a receptive stigma and absorb moisture from the stigmatic exudate. The pollen tube emerges from one of the colpi (apertures) and grows through the style toward the ovary, carrying the male gametes for fertilization. In vitro pollen germination can be achieved on sucrose-based media (10-20%), often supplemented with boric acid (H_3BO_3) and calcium nitrate [$Ca(NO_3)_2$] to enhance tube growth. Germination rates vary from 50–80%, depending on genotype and environmental conditions. Pollen tube growth rate is a critical determinant of fertilization success. Optimum temperature for pollen tube growth lies between 25-30°C, while extreme temperatures inhibit elongation and result in poor fruit set.
- **Role of hormones in flowering:** Flowering in chilli is a complex physiological process regulated by endogenous plant hormones, which control the initiation, differentiation, and development of floral buds.

Auxins (IAA) play a crucial role in cell elongation and meristem differentiation, promoting the transition from vegetative to reproductive growth, although excessive levels may inhibit floral initiation.

Gibberellins (GA₃) stimulate floral meristem differentiation, advance flowering time, and increase the number of flowers per plant, often interacting with auxins to regulate floral organ development, while excessive gibberellin may favor vegetative growth over flowering.

Cytokinins such as zeatin and BAP, enhance cell division at the shoot apex, improve flower bud initiation, and reduce flower drop by promoting nutrient mobilization to developing flowers.

Abscisic acid (ABA) is commonly produced under stress conditions like drought or salinity, can delay flowering and induce flower and fruit drop, while ethylene often triggers premature flower abscission, negatively affecting fruit set.

The overall flowering pattern in chilli is determined by the synergistic and antagonistic interactions among these hormones, where auxin and gibberellin promote floral initiation, cytokinins enhance flower differentiation, and ABA and ethylene act as inhibitors under stress. Exogenous application of appropriate hormones or growth regulators can therefore be effectively used to optimize flowering, improve flower retention, and increase fruit yield in chilli cultivation.

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