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Flower Bud Formation in Fruit Crops

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Flower formation is the initial step toward gaining an economic output. Fruit production starts with the formation of flower buds. A crucial stage of fructification is flowering. Flower bud formation occurs in five stages i.e. induction, initiation, differentiation, maturation, and anthesis. Flower bud formation is influenced by both internal circumstances and external environmental influences. The more the production of flower the more chance of setting fruit. Deficiencies of some hormones and nutrients causes bud dormancy which can be reduced by the help of growth hormones and some regulators which enhances complete flower formation. This paper will help to understand the basic physiology behind the flower bud formation, biochemical changes during bud formation as well as factors affecting the bud formation in fruit crops.

Keywords: Flower bud; fruit crops; meristem; reproductive; vegetative.

1. INTRODUCTION

A fully developed, ripened ovary and its contents make up a fruit. An ovary is a reproductive organ that contains Fruit bloom. Fruit is a tree or other plant's delicious, fleshy harvest that contains seeds and can be consumed as food. Fruit production starts with the formation of flower

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buds. A fruit is the main barrier to flowering in most perennial plants, including evergreen and deciduous species [1]. A crucial stage of fructification is flowering. If there are no flowers, there will be no fruit, and if there are few flowers developed, crop load may be constrained [2]. A flower is the major part of the plant that ultimately helps to gain economic yields as well as the raw material for producing seeds which help in producing offspring for the next generations. Natural farming practices result in crops that reproduce well. When crops are cultivated in climates to which they are not acclimated or when cropping levels are not met economically, problems occur. Economic yields are mostly dependent on sufficient flowering and the subsequent fruit set from those flowers [3]. The process that leads to the commitment of meristematic cells to the production of reproductive structures is known as flower bud formation. It is influenced by both internal circumstances and external environmental influences. Fruit crop flowering plays a significant economic role. The quantity and caliber of the developed flower buds determine the yield. The complex developmental process of flowering involves several internal and external signals that regulate several physiological and morphological stages. Before floral differentiation, fertilization, fruit set, and fruit development, flower initiation is the earliest and most crucial step in the crop formation. Each of these processes could be a constraining element in crop formation [4].The term "induction or formation" is described as being initially used at the time that external influences start the flowering process, causing a shift in the pattern of development of the buds that eventually commit to becoming flowers. The term "auto-inductive" was created to characterize plants that blossom without any particular environmental indication [2]. Plants can be categorized as annuals or perennials based on their type or mode of growth. We discovered that the majority of fruit species have perennial growth mechanisms when researching fruit crops. Although annual and perennial plants differ in many functions the genetics of flower induction and the development of floral organs appear to be the same [5]. A plant's life cycle can be separated into two phases: the vegetative phase, which is decided by a seedling's incapacity to blossom, and the generative phase, which is determined by a seedling's ability to flower. The transition phase refers to the period between the vegetative and generative stages. Endogenous and external variables can cause or suppress the shoot meristem's switch from producing leaves to developing reproductive organs during the time of floral transition [4]. In mango, it has been proven that flower bud differentiation depends on the tree's "on" and "off" year phases rather than on the first cessation of shoot growth, observations in the following years provided additional evidence for this theory. A high concentration of auxin-like compounds may stimulate flowering by either limiting the efficiency of GA or by reducing the permeability of the cell membrane. It was discovered that the activity of GA-like chemicals was larger in the "off" year. According to reports, potassium nitrate (KNO3) effectively induces flowering in mango by boosting nitrate reeducates activity and promotes the synthesis of ethylene (Chadha & Pal , 1994). In plants that require cold and are photoperiodic sensitive, there was an increase in glucose levels in the apical bud in conjunction with the floral transition. Ito et al., [6]. demonstrated how sugar metabolism contributed to the development of pear flower buds. Citrus flower formation has been said to be limited by carbohydrate levels [7].

Since girdling is known to result in a buildup of carbohydrates within the girdled branch, the promotion of flower production after girdling treatments has been viewed as key evidence supporting this claim.According to Ito et al., [6] a lot of carbohydrates were ingested throughout the beginning and subsequent stages of the development of floral organs. As a result, variations in carbohydrates play a significant part in how plants create flowers. This review paper will help to understand the basic physiology behind the flower bud formation, biochemical changes during bud formation as well as factors affecting the bud formation in fruit crops.

2. METHODOLOGY

This review was conducted utilizing data from Google Scholar, Research Gate, and technical reports, all of which were shared with the authors. All articles are selected based on the flower bud formation and its processes, positive and negative factors of influencing flower bud formation to complete flower formation and finally fruit setting. Despite the vast number of articles found for each subtopic, only a few were chosen for relevance and permitted data of time frame from 1976 to 2024.

3. MECHANISM OF FLOWER BUD FORMATION

Once a plant family reaches adulthood, the change from vegetative to reproductive development occurs suddenly. This cycle, which begins with the commencement and development of blooms and ends with the generation of fruit and seeds, is frequently initiated by environmental cues and coordinated by internal mechanisms [5]. Flowering bud formation and the flowering mechanism are different for different fruits which are mostly governed by genotypes as well as by environmental factors [8]. Typically, a fresh vegetative flush will emerge and mature before flowering. Winter starts after a dry season and a decrease in rainfall, which causes flowers to bloom especially in mango. Three flushes of flowering typically take place throughout the season. It manifests as sporadic, transient flushes from lateral and apical buds. A healthy mango shoot will typically produce four to five flushes every year, depending on the cultivar and growth environment [9]. The majority of commercially important apple cultivars primarily produce fruit on spurs [10]. These spurs constitute the major leaf region of the trees from the "green apex" stage through full bloom. They also sprout some leaves later; the entire spur leaf area forms up to one month after flowering [11]. According an experimental data, the development of the floral stimulus, the absence of which can cause a lack of flowering or biennial bearing in many mango cultivars, is somehow related to the maturation of terminal shoots and the accumulation of carbohydrates in the shoot apex. An extremely controlled process, the beginning of flowering involves temporal and geographical interactions between external and internal elements. Temperature and day length (in actuality, the duration of the night) are two external signals that are important to the blossoming process. These work to encourage flower initiation, along with endogenous variables including developmental stage and floral gene activity. Annual plants, which flower and produce seeds in a single year, have seen the majority of recent advancements in this field, whereas perennial plants, whose flowering spans several years, have received less attention. Meristems are essential to the process of floral initiation. These are collections of undifferentiated cells that develop into axillary shoots, internode tissue, lateral organs (like leaves), lateral organs (like flowers), and flowers. In indeterminate structures, meristem cells continue to proliferate. Therefore, whether flowering occurs depends on the type of cells produced and their final developmental fate as a component of vegetative or reproductive structures [5]. The time of the start of flowers can also be influenced by a plant's developmental stage. This is especially true for species of perennial woody plants, which typically have distinct juvenile and adult periods. Extreme morphological, physiological, and biochemical changes accompany the move from the juvenile to adult phases in woody perennials; the most noticeable of these is the appearance of blooming branches [12].

Meristems establish reproductive competence during the juvenile stage of plant development, enabling them to recognize and react to signals that cause flowering. Hanke et al., [4]. The timing of flowering within a species can vary greatly due to genetic variability or variations in the environment. Even annual herbaceous plants cannot flower until they have passed a brief juvenile phase of reproductive incapacity [13].The stages of flowering include floral induction, flower initiation, flower differentiation, and anthesis (blooming). The meristem development shifts from the vegetative to the reproductive phase during flower induction. The apical meristem picks up flower signals during this time, turning on the genes needed for flower development. During flower initiation several of histological changes take place yet there are no discernible morphological modifications. In this stage, buds are receptive to stimuli that will decide how they develop. Regardless of the internal or external factors that can affect flower induction, when a bud is made to become reproductive, the process of floral organ development will occur irrevocably [14]. Modifications to buds' morphology represent flower differentiation. Beginning with the emergence of floral primordia in the bud it progresses to the maturation of floral organ primordia. About 12 weeks after full bloom, the dome-shaped apex of the bud constantly distinguishes distinct flower varieties [15]. As a result, sepals, petals, stamens, and carpels are differentiated, and the center of the apex develops into a "King" flower surrounded by four lateral blooms. Winter dormancy causes flower buds to gain weight and start maturing. Up until the spring after that, when flowers blossom, floral organ growth and development continue. Water shortages, hot temperatures, nutrient inadequacies, defoliation, insufficient chilling temperatures during dormancy, and freezing injuries will slow down the rate of development and reduce the quality of flower buds. When compared to apple trees exposed to higher root zone temperatures, those growing in regions with root zone temperatures below 15°C experience delayed bud break and up to 20% fewer clusters [16]. Apple, however, benefited from increased air temperature after full bloom, but blossom quality as measured by the quantity of well-developed flowers per cluster tended to deteriorate with rising temperature [17]. Apple juvenile shoots solely develop vegetative buds, but mature shoots sequentially develop both vegetative and generative (floral) buds. The shoot apex contains the shoot meristem, the plant's primary growth center, which is surrounded by immature primordia that, prior to floral induction, develop into leaves and then into flowers (Hanke et al., 2007).

Photoperiod, vernalization, autonomous, and gibberellin (GA), which combine environmental and endogenous signals to determine the timing of blossom initiation, are examples of genetic pathways that occasionally overlap [19]. A checkpoint for flowering time control, which is made up of at least three genes collectively known as floral pathway integrators. FLOWERING LOCUS T (FT), LEAFY (LFY), and SUPPRESSOR OF OVEREXPRESSION OF CONSTANS 1 is where the various pathways all converge (SOC1). Such floral meristem identity genes as APETALA1 (AP1), FRUITFUL (FUL), CAULIFLOWER (CAL), LFY, and SEPALLATA4 (SEP4) are activated by the floral pathway integrators, and their activation results in the conversion of vegetative apices to inflorescence meristems. Following the expression of downstream floral organ identity genes, which results in the development of flowers, the specification of flowering fate in meristems [5]. The sequential growth of flower organ primordia, beginning with sepals and ending with carpels, is caused by the differentiation of the floral meristem once it has been created. These many floral organs of dicotyledonous plants are typically grouped in four concentric rings known as whorls: sepals are located in the first whorl, followed by petals in the second whorl, stamens in the third whorl, and carpels in the fourth whorl. By examining global gene expression, it was determined that shoot bending had a notable impact on the expression of genes related to cytokinin, indole-3-acetic acid, gibberellin synthesis, and signaling, influencing processes such as cell division, differentiation, bud development, and flower initiation [20]. The joint examination of metabolomic and transcriptomic data elucidated the important regulatory roles of pathways like arginine and proline metabolism, cyanoamino acid metabolism, glutathione metabolism, phenylalanine metabolism, isoquinoline alkaloid biosynthesis, pyrimidine metabolism, and others in driving the development of flower buds and leaf buds in A. bulbifer [21]. The expression patterns of genes including ZjICE1, ZjCO6, ZjSOC1, and ZjFT were characterized by increased levels during the later developmental stages in both tissues, suggesting their potential role in regulating the onset of flowering and ZjPIF4 serves as a key regulator in initiating the floral initiation process [18].

4. BIOCHEMICAL ADJUSTMENTS DURING FLOWER DEVELOPMENT

The differentiation of the flower is based on the production of a particular ribonucleic acid, and it has been demonstrated that in apple, the transition of the bud from the vegetative stage to the reproductive one is immediately followed by changes in the nucleic acid metabolism. Flower bud differentiation will not occur if the production of this particular nucleic acid is blocked by particular substances . Before flower initiation, studied the RNA content of flower buds and reported on a correlation between the quantity of RNA and the frequency of flower bud differentiation. A second peak of rise was observed during the start of floral differentiation in August after the initial high of RNA content was reached during flower induction till mid-June.

The process of flower bud differentiation is closely linked to nucleic acids, requiring a significant amount of these compounds. The levels of total nucleic acid, DNA, and RNA gradually increased during the physiological differentiation phase. The RNA/DNA ratio peaked concurrently with the RNA content. In floral buds, the concentrations of total nucleic acid, RNA, DNA, and RNA/DNA ratio exceeded those in vegetative buds. As flower induction occurred, the soluble protein content in the leaves of floral shoots increased, whereas during flower differentiation, this content also rose by Liu et al. (2011). Li (2005) study concluded that protein synthesis plays a crucial role in promoting flower bud differentiation, necessitating a substantial intake of protein during this process. The study observed a gradual increase in DNA and RNA concentrations as well as the RNA/DNA ratio during the floral bud differentiation stage of mango, with the elevated nucleic acid levels aiding in mango's floral bud differentiation [22].

5. FLOWER BUD DEVELOPMENT FACTORS AND CIRCUMSTANCES

From induction until anthesis, the growth of flower buds is influenced by a variety of situations and causes, each of which, at a certain time, is responsible for the production of a flower bud.

5.1 Internal Factors

Fruit trees' distinct flower bud differentiation was explained by the C/N-ratio theory. Inhibited by excessive N fertilization, flower development is favored by high C/N ratios. According to a hormone called florigen induces flowering. According to Searle (1965), florigen, which is created in leaves and transferred to buds, controls how often photoperiodically sensitive plants blossom. A positive role for florigen was described as activating genes, and a negative role as inhibiting gene-repressors. The search for a florigen-specific mRNA evidence involved multiple attempts. Wellensiek, [23] assumed that the flower induction in buds is influenced by flower stimulating compounds as well as by inhibiting compounds. Different hormones regulate flower formation interactively. Auxins are both promoting and inhibiting flower formation. Cytokinins are associated with promotion of flowering in apple. The effect of abscisic acid remains unclear. Ethylene affects flowering in a stimulating manner. Of all currently known hormones, gibberellins (GA) are most strongly associated with flowering. In fruit tree species, GA treatments have been demonstrated to limit the growth of flower buds, but at the same time, GA appears to be essential for floral development [24]. The development of vegetative and reproductive plants, which are strongly associated to alternate bearing, is evidently regulated by GA.

5.2 Environmental Factors

Vernalization causes flowering in many fruits. The photoperiod and particular temperature circumstances play a significant role in controlling tree blooming because they serve as inductive conditions for the onset and termination of dormancy, which affects both vegetative growth and floral development. Tromp, [25] hypothesized that the first four to five weeks following full bloom i.e., during flower initiation are of especially considerable relevance for flower creation. After an apple's full bloom, (Zhi-fang et al., [17], investigated the impact of temperature on the development of flower buds, stalk growth, and bud morphogenesis at various times. In this study, it was discovered that raising temperature increased blooming when administered seasonally, six to seven weeks after full bloom, on spurs, and on one-year-old shoots, however the impact was most significant in the 13 to 20 degree range.

5.3 Fruit-Bearing Branches

On several kinds of fruit-bearing branches, variable flower bud initiation times have been observed. On perennials, bud differentiation normally begins first, on spurs, a little later on the more youthful and active ones, and at the very last, on the shoots. When flowers begin to form on identically positioned (and the same age) branches, they can do so rapidly and nearly simultaneously in all of them or they can do so over a significantly longer period of time [26].

5.4 Shoot Growth

The development of the shoots is frequently correlated with the differentiation of flower buds. For the commencement of flowers, growth is thought to have to come to an end Hirst & Ferree, [27]. After the bloom, the shoots may continue to grow while the spurs stop growing 2–4 weeks later. 'Golden Delicious' apple spur and axillary flower initiation, according to Luckwill & Silva, [26], happens about two weeks after the growth of the long shoots stops, but it happens one month later in the terminal buds of the shoots. The development of floral buds and vegetative growth are thought to be adversarial processes.

6. CONCLUSIONS

Flower bud formation is an essential step that ultimately leads to production of fruits. For any horticultural crop including fruits the ultimate or final product which provide the economic value is the production of fruits. More the production of flowers more will be the production of fruits. Flower bud formation starts from phase of bud induction and completes in anthesis. Simply we can say flower bud formation is the process of transition of vegetative phase to reproductive phase. Formation as well as opening of the bud can also be affected by the presence of some inhibitors or any hormonal or chemical or nutritional deficiency at the point of bud emergence which is known as bud dormancy thus to overcome from this hindrance different treatment of growth hormone's or nutrition are applied to the plant that helps in rapid bud induction and complete as anthesis which results in a complete flower formation. This review article helps in understanding these fluctuations is essential for devising methods to enhance fruit quality and yield, reduce losses, and promote sustainable production practices. Collaborative research and innovation in these domains are imperative for securing a resilient future in fruit crop production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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