

Integrated Regulation of Bud Dormancy in Fruit Trees: Environmental, Molecular, Hormonal and Cellular Perspectives

Garima Vashisth^{1*}, Sanjeev Kumar¹ and Ayush Vashist²

¹Department of Basic Sciences, College of Forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry Nauni Solan, Himachal Pradesh, India

²Department Soil Science and Water Management, College of Horticulture and Forestry Neri, Dr. Yashwant Singh Parmar University of Horticulture and Forestry Nauni Solan, Himachal Pradesh, India

INTRODUCTION

Bud dormancy is a crucial adaptive function that enables fruit trees such as the *Malus*, *Prunus* and *Pyrus* to withstand freezing temperatures in the winter and to grow again when the environmental conditions enable this to happen. The depth of the dormancy, its intensity and how fast dormancy ends determines the actual timing of the budbreak and the synchronization of flowering and ripening processes. While previously assumed to be a simple reaction to cold storage accumulation or hormonal control, modern transcriptomic, genomic, epigenetic and metabolic research suggests that dormancy is a chain reaction of physiological processes conditioned by different interconnected regulatory systems. The regulation of this chain of processes involves adaptational processes, as well as the internal processes of the plant (the genetic processes and hormonal processes). The dormancy process can be categorized into three physiological steps: Para-bud dormancy: Growth inhibition owing to physical or hormonal reasons outside the bud (Lang et al., 1987). Endodormancy: A form of deep physiological standing just as a response to signals from the bud coming from inside, which can only be released via a prolonged winters experience. Ecodormancy: Phase that is taking place just after the fulfillment of chilling demands as it is still blocking shoot growth merely with unfavorable outside temperatures (Considine & Foyer, 2023). Instead of just sitting there in a quiet state, dormant buds undergo the process of molecular components reprogramming as well as carbohydrate removal, chromatin modification and signals of oxidative bacteria. This explains the fact that if winters are not harsh, winter chilling requirements will be satisfied in an unusual way, thus leading to delayed or uneven budbreak as well as poor fruit set or even low harvest.

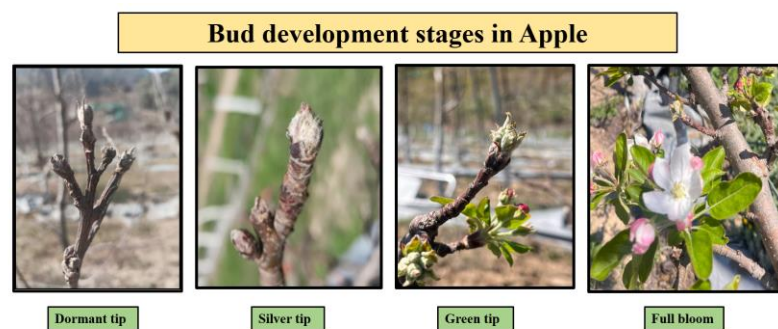


Fig. 1 Different bud development stages in apple.

1. Environmental Drivers of Bud Dormancy

1.1 Photoperiodic Regulation

The length of the day, or photoperiod, plays a role as the biological clock telling many temperate trees when to start and stop growing. The trees perceive the changes in the length of the day through proteins, that can sense light, which connect the daily light patterns and the biological clock (Maurya et al, 2020). During the long days of summer, this biological system confirms the production of the protein known as FT. The FT protein travels straight to the tips of the trees, thus stimulating their growth. As autumn comes and the days become shorter, the intensity of light falls below the value necessary for the operation of this growth mechanism. That is when the tree begins to decrease FT level and switch to the use of dormancy genes (like BRC1 and DAM) and at the same time stimulate the production of the hormone ABA. As a result, the tree stops growing, develops the protective layer for the bud and becomes dormant. But it should be noted that not all types of fruit trees are characterized by the same reactions.

1.2 Temperature Responses and Chilling Accumulation

Temperature serves as the primary natural signal that leads fruit trees—such as apple, pear, peach, cherry, plum and apricot trees—into a state of winter dormancy, allows them to monitor winter cold and wakes them in spring. As temperatures fall during autumn and day length decreases, trees stop producing new shoots and generate buds that are sealed tightly in preparation for freezing weather (Baumgarten et al., 2021). This winter dormancy prevents soft and delicate buds from being damaged by freezing temperatures and can only be interrupted after certain conditions related to winter cold are satisfied (usually temperatures below 10° C are sufficient). Temperature effects will trigger a biological chain reaction: winter cold will activate some genes responsible for growth and will deactivate others, allowing the cells to stop inhibiting growth. Furthermore, winter cold will lead to resetting gene sequences, changes in cellular structures and shifts of hormones. As soon as the tree receives the required amount of winter cold regardless of its gene characteristics, it will come out of winter dormancy and simply wait for the beginning of spring and warm weather (with related variables like growing degree days) to trigger the blossoming and formation of shoots (Malyshev et al., 2022).

1.3 Heat Requirement during Ecodormancy

After winter conditions have sufficiently cooled a tree, the process of coming out of dormancy begins. Trees undergo a period of endodormancy and enter into ecodormancy where they continue their growth depending on enough warmth in the spring. The temperature above which the buds burst open is known as Growing Degree Days (GDD). GDD decreases after Peak Dormancy Depth (PDD), which varies among organisms and is hard to calculate due to slightly changing climate conditions. As the temperature rises in spring, the buds come out of dormancy. Once buds come out of their dormant state, they start breaking down starch in order to generate heat for the process of growth. This process occurs thanks to hormones that regulate the transition from winter to spring.

2. Hormonal Signaling Networks and Crosstalk

The shift of tree buds from winter rest to spring activity is controlled mainly through a sensitive balance of hormones in plants. In autumn, with the onset of short days and cooler temperatures, the level of abscisic acid (ABA), also known as the “sleep hormone” in plants, increases. A high concentration of ABA inhibits growth and cell division and maintains dormancy by triggering the changes in bud structures aimed to ensure protection. ABA is also important for the production of callose that blocks water, sugar and growth signals from moving through the cells. With the advance of winter and after the necessary chilling period has passed, the levels of ABA decrease while gibberellins (GA) become active. GA facilitates the breakdown of callose and breaks down inhibitory signals for growth, which permits cell communication and division. Nevertheless, GA can cause the release of dormancy only after a sufficient chilling period (Yang et al., 2020). Cytokinin, auxin, ethylene, brassinosteroids and jasmonate also play an important role in bud awakening and the amount of each hormone influences different plant species and plant growth phase. Finally, due to the shifting ABA-GA balance, bud dormancy can be maintained during winter and growing in spring (Hao et al., 2019).

3. Carbohydrate Regulation

Carbohydrates stored in woody stems and trunk tissues have both food and survival utility in winter. Upon the arrival of winter, enzymes like α -amylase, β -amylase and starch phosphorylase are activated in cold temperatures, which converts starch into simple soluble sugars such as sucrose, glucose and fructose. During midwinter, sugars act as natural antifreeze and lower the freezing point of water in plant cells and protect cell membranes from damage. When spring comes, the warmer temperature will further speed up this process and allow buds to acquire energy and resources for cell division, swelling and shoot growth. For fruit trees like apples, pears, peaches and cherries, sugar alcohol sorbitol has a significant role. Sorbitol accumulates in buds during winter, thus helping cells remain hydrated and stable during freezing temperatures. When enough chilling in winter occurs and spring warmth comes, sorbitol dehydrogenase (SDH) transforms sorbitol into fructose, thus providing buds with an instant energy source for growth.

4. Advanced Technologies, Breeding and Management

During the winter period, dormant shoots attain optimum cold tolerance owing to dehydration, sugar accumulation and membrane stabilization processes. Germplasm banks use this particular physiological state of plants for cold storage of horticultural genetic materials. By freezing the buds of kept in winter dry branches, scientists can utilize the method of cryopreservation (in the liquid nitrogen (-196 degrees Celsius)) to get viable bud shoots without structural damage and thus create a more effective approach towards genetic diversity preservation compared to field orchards.

5. Horticultural and Biotechnological Applications

In countries with warm temperatures having mild winters, trees may face challenges in germinating and blooming properly during early spring. To deal with the issue, farmers and horticulturists may make use of the substances called rest-breaking agents which can include hydrogen cyanamide (HC, better known commercially as Dormex), oils obtained from minerals and potassium nitrate. These preparations trick the trees into thinking that they are experiencing stress and therefore can start growing. Hydrogen cyanamide acts on the process of oxidation that causes the levels of reactive oxygen species (ROS) to raise for a short time and then leads to the decrease of ABA content in the tissue making the substances promoting growth, for example, gibberellins and cytokinins, to work. The produced ethylene and hydrogen cyanide (HCN) during the process of these substances working, also contribute to breaking the rest stage of tree buds. For the wait of a long-term solution, scientists are engaged in breeding fruit trees which are better suited for the climates of contemporary times thanks to marker-assisted breeding. The processes lead to the identification of genes such as DAM and SVL which are important for rest-breaking.

Conclusion

Deciduous fruit trees undergo dormancy in the buds, which entails a complex interaction of various environmental indicators, hormones and metabolic processes. The ABA–GA equilibrium is responsible for maintenance of dormancy during the winter and release of buds from dormancy in spring. However, warmer winter may interfere with chilling demands, resulting in flowering being delayed or occurring at a different time.

References

- Baumgarten F, Zohner CM, Gessler A, Vitasse Y. 2021. Chilled to be forced: the best dose to wake up buds from winter dormancy. *New Phytologist*, 230(4), 1366–1377.
- Considine MJ, Foyer CH. 2023. Metabolic regulation of quiescence in plants. *The Plant Journal*, 114(5), 1132–1148.
- Hao X, Tang H, Wang B, Yue C, Wang L, Zeng J, Yang Y, Wang X. 2019. Gene characterization and expression analysis reveal the importance of auxin signaling in bud dormancy regulation in tea plant. *Journal of Plant Growth Regulation*, 38(1), 225–240.
- Lang GA, Early JD, Martin GC, Darnell RL. 1987. Endodormancy, paradormancy and ecodormancy: Physiological terminology and classification for dormancy research. *HortScience*, 22(3), 371–377.
- Malyshev AV, Maaten EVD, Garthen A, Maß D, Schwabe M, Kreyling J. 2022. Inter-individual budburst variation in *Fagus sylvatica* is driven by warming rate. *Forests*, 13(1), 1–11.

- Maurya JP, Bhalerao RP. 2020. Branching regulator BRC1 mediates photoperiodic control of seasonal growth in hybrid aspen. *Current Biology*, 30(1), 122–126.
- Yang Q, Gao Y, Wu X, Moriguchi T, Bai S, Teng Y. 2020. ABA-responsive ABRE-BINDING FACTOR3 activates DAM3 expression to promote bud dormancy in Asian pear. *Plant, Cell & Environment*, 43(6), 1360–1375.

