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Phenology-Guided Foliar Bioregulation of Guava under Moisture Deficit: Physiological Mechanisms and Critical Developmental Windows

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Guava (*Psidium guajava* L.) is an important fruit crop whose growth, flowering, fruit setting and fruit development are strongly influenced by water availability. Moisture deficit can disturb plant water status, stomatal behavior, canopy temperature, chlorophyll stability, photosynthesis and antioxidant balance, resulting in reduced physiological performance during sensitive developmental stages. Guava phenology provides a useful framework for identifying these stage-specific responses and for improving the timing of crop-management practices. This review summarizes the major phenological stages of guava and discusses their relationship with moisture-deficit stress and foliar bioregulation. Particular attention is given to three important developmental windows: early bud development, flower-bud appearance or reproductive transition and the petal fall–fruit-set transition. The potential roles of salicylic acid, melatonin and glutathione in supporting stress tolerance through signaling, osmotic adjustment, antioxidant defense and protection of photosynthetic processes are also discussed. The review highlights that foliar interventions based on actual phenological stages may be more biologically meaningful than application based only on fixed calendar date days. However, further field validation is required to identify suitable bioregulator, dose and phenological-stage combinations under different cultivars, seasons and moisture conditions. Phenology-guided foliar management may provide a useful framework for investigating abiotic stress tolerance, water-use efficiency and sustainable guava production.

Introduction

Guava (*Psidium guajava* L.), belonging to the family Myrtaceae, is an important tropical and subtropical fruit crop valued for its adaptability, productivity and high nutritional quality. The fruit is a rich source of vitamin C, dietary fibre, carbohydrates, minerals and bioactive compounds such as phenolics and flavonoids, which contribute to its antioxidant and functional food value (Khan *et al.,* 2025). Sustainable guava production, however, largely depends on efficient water management, particularly in semi-arid regions where irregular rainfall and high evaporative demand frequently expose the crop to moisture stress.

Deficit irrigation has been suggested as an important water-saving strategy in fruit crops, but its success depends on the intensity and duration of stress as well as the sensitivity of the crop at different developmental stages (Galindo *et al.,* 2018) [10]. In guava, ETc-based irrigation levels have been reported to influence plant water relations, fruit growth, yield and irrigation water productivity (Jat *et al.,* 2022; Lakhawat *et al.,* 2024; Manjunath *et al.,* 2024). Therefore, water management should be evaluated not only in terms of the quantity of water applied but also in relation to the physiological and phenological stage of the crop.

Phenology provides a useful framework for understanding stage-specific crop responses. Guava passes through distinct phases of bud development, vegetative growth, flowering, fruit setting, fruit enlargement and ripening. Salazar *et al.,* (2006) described sixteen phenological stages of guava and related them to the BBCH General Scale and Fleckinger codes. However, the timing of these stages may vary with pruning, season and environmental conditions. Singh *et al.,* (2015) also reported changes in guava flowering phenology following pruning, indicating that crop development should be treated as a dynamic process rather than a fixed calendar schedule.

Foliar bioregulators such as salicylic acid, melatonin and glutathione may improve plant tolerance to moisture stress through regulation of water relations, photosynthesis and antioxidant defense (Hasanuzzaman *et al.,* 2017; Himanshu *et al.,* 2024; Roque *et al.,* 2025). However, their effectiveness may also depend on the phenological stage at which they are applied.

Phenological development of guava

Phenology describes the timing and sequence of vegetative and reproductive developmental stages. In guava, the growth cycle progresses from bud break, development and leaf emergence to flowering, fruit setting, fruit growth and ripening. Salazar *et al.,* (2006) identified sixteen phenological stages in guava and related them to the BBCH General Scale and Fleckinger codes. However, the timing and duration of these stages may vary with cultivar, pruning time, season, edaphic factors and environmental conditions (Singh *et al.,* 2015; Sharma *et al.,* 2017). Therefore, phenological stages should be considered as developmental windows rather than completely fixed days. Recent BBCH-based work has further standardized various developmental of guava and supports the use of phenological coding for comparing stages of crop development across cultivars and environments (Sharma *et al.,* 2026).

Bud and vegetative development

After the stress period, pruning is carried out. With the onset of irrigation, buds begin to emerge, followed by bud swelling and shoot growth, leaf emergence, and complete leaf development. The development of a healthy leaf canopy is important because leaves provide the photosynthetic assimilates required for subsequent flowering and fruit development. The duration of leaf flushing and vegetative growth varies among guava genotypes and environmental conditions (Alfia *et al.,* 2017; Singh *et al.,* 2020). Pruning also influences the timing of new shoot development and subsequent flowering (Singh *et al.,* 2015).

Flower-bud development and flowering

Appearance of flower buds represents the transition from vegetative to reproductive growth. Flower-bud development, flowering duration and time to peak flowering vary among cultivars and seasons (Sharma *et al.,* 2017; Sahoo *et al.,* 2017; Koti *et al.,* 2026). Singh *et al.,* (2020) also reported considerable variation in flowering behavior among cultivated and wild *Psidium* genotypes. Since the C: N ratio plays an important role in floral development, and floral development requires adequate assimilate availability and optimal plant water status, this stage may be particularly critical under moisture-deficit conditions or water-deficit conditions (Gomasta *et al.,* 2024).

Pollination, petal fall and fruit setting

Flowering is followed by anthesis, pollination, petal fall and fruit setting. Pollination and fruit establishment are influenced by pollen viability, temperature, humidity and physiological condition of the plant (Sharma *et al.,* 2011; Alves and Freitas, 2007; Nithishni *et al.,* 2026). The period between petal fall and fruit setting is especially important because young fruits begin to develop as active sinks for carbohydrates. Therefore, this stage can be considered a critical fruit-establishment window for evaluating stress and foliar interventions.

Fruit growth and development

After successful fruit set, guava fruits progressively increase in size, weight and biochemical constituents (El-Buluk *et al.,* 1995; Selvaraj *et al.,* 1999). Mercado-Silva *et al.,* (1998) reported that fruit growth in guava follows a double-sigmoid pattern, with periods of rapid and relatively slow growth during development.

The duration from fruit set to harvest also differs among cultivars and growing conditions. Adequate water and assimilate supply during this phase are therefore important for proper fruit enlargement.

Maturation, ripening and phenological variability

During maturation and ripening, guava fruits undergo various physical and biochemical changes, including changes in colour, firmness, sugar content, total soluble solids, and organic acid content. (Patel *et al.,* 2015; Mondal *et al.,* 2009). The timing of maturity varies with cultivar, season and environmental conditions (Sahoo *et al.,* 2017). Thus, days after pruning should be used as an approximate reference, while the actual phenological stage should guide crop-management decisions.

Figure 2 shows the progression of guava phenology from emergence of bud to fruit ripening and its relationship with three important intervention windows. The early bud-development, flower-bud emergence and petal fall–fruit-set transition stages represent distinct physiological phases where targeted foliar intervention may be useful. These timings should be considered approximate developmental windows rather than fixed days.

Moisture-deficit responses across phenological stages

Moisture deficit affects guava by reducing soil-water availability and disturbing normal plant physiological functions. The response may differ with phenological stage because vegetative growth, flowering, fruit set and fruit development have different water and assimilate requirements (Lacerda *et al.,* 2026). Under prolonged stress, reduced plant water status may affect photosynthesis, reproductive development and finally fruit productivity (Jat *et al.,* 2022; Usman *et al.,* 2022). The effect of drought also depends on developmental stage because crop water use, transpiration and assimilate demand change during growth (Vadez *et al.,* 2024).

Plant water status and relative leaf water content

Relative leaf water content (RLWC) is an important indicator of plant hydration under moisture stress. Reduced soil-water availability generally decreases leaf water content and cellular turgidity, which may restrict leaf expansion and physiological activity.

In guava, lower water availability has been associated with reduced plant water status and growth, whereas adequate irrigation helps to maintain higher leaf hydration (Jat *et al.,* 2022; Usman *et al.,* 2022; Singh *et al.,* 1997). Maintenance of plant water status is particularly important during flowering and fruit establishment because these stages require continuous physiological activity.

Stomatal regulation and canopy temperature

Under water deficit, plants generally reduce stomatal conductance to limit transpirational water loss. This response helps conserve water but also reduces CO_2 entry and transpirational cooling. As a result, leaf or canopy temperature may increase under moisture stress. Canopy temperature can serve as a rapid, non-destructive indicator of crop water status, provided that measurements are interpreted together with air temperature, vapour-pressure deficit, radiation, wind speed and measurement time. (Jat *et al.,* 2022; Roque *et al.,* 2025). Thermal and canopy-temperature measurements are also increasingly used as rapid, non-destructive indicators of crop water stress (Cho *et al.,* 2024).

Chlorophyll and photosynthetic stability

Moisture stress can negatively affect chlorophyll pigments and photosynthetic activity. Reduced chlorophyll content limits light absorption and may decrease the production of assimilates required for vegetative growth and fruit development. Guava plants exposed to water deficit have shown reductions in chlorophyll-related traits, gas exchange and photosynthetic performance (Usman *et al.,* 2022; Roque *et al.,* 2025). Therefore, maintenance of chlorophyll and photosynthetic stability is important for sustaining productivity under limited water availability.

Osmotic adjustment and antioxidant defense

Plants also develop biochemical mechanisms to tolerate moisture stress. Accumulation of osmolytes such as proline can help maintain cellular water balance, while antioxidant systems protect cells from excessive reactive oxygen species produced during stress. Strong antioxidant defense helps protect membranes, chloroplasts and other cellular components from oxidative damage (Hasanuzzaman *et al.,* 2017; Usman *et al.,* 2022; Foyer and Noctor, 2011; Noctor *et al.,* 2012). These protective mechanisms may therefore contribute to better physiological functioning during critical phenological stages.

Figure 3 summarizes the relative importance of major physiological responses across guava phenological stages under moisture deficit. The reproductive transition and petal fall–fruit-set stages show a comparatively high physiological relevance because water relations, photosynthesis and antioxidant defence operate simultaneously during these stages. The ratings represent a qualitative literature-based synthesis rather than experimentally measured values.

Critical phenological windows for foliar intervention

The response of guava to foliar bioregulators may vary with the developmental stage because plant water requirement, assimilate demand and stress sensitivity change during the crop cycle. Therefore, foliar applications may be more effective when synchronized with important phenological transitions rather than applied only according to fixed calendar dates. Variation in guava phenology with cultivar, season and pruning further supports the use of stage-based intervention windows (Salazar *et al.,* 2006; Singh *et al.,* 2015; Singh *et al.,* 2020).

Early bud-emergence window

The early bud- emergence stage begins soon after pruning and represents the establishment of new vegetative growth. At this stage, developing shoots and leaves require adequate water and metabolic activity for canopy formation. Stress during this period may restrict leaf development and reduce the photosynthetic surface available for later reproductive growth (Abrar *et al.,* 2022). Therefore, the early bud-development stage can be considered an important first window for foliar interventions aimed at mitigating stress (Jayswal *et al.,* 2019; Santhoshkumar *et al.,* 2022).

Flower-bud appearance and reproductive-transition window

Appearance of flower buds marks the transition from vegetative to reproductive development. During this stage, the plant requires sufficient water, photosynthetic assimilates and physiological stability to support floral development and subsequent flowering. Flowering behaviour in guava varies with genotype, pruning and environmental conditions (Sharma *et al.,* 2017; Singh *et al.,* 2020).

Therefore, flower-bud appearance may provide a useful biological stage for applying foliar bioregulators aimed at protecting reproductive development under moisture stress.

Petal fall–fruit-set transition window

The period between petal fall and fruit setting is a critical reproductive transition because young fruits begin to establish as active sinks for water and assimilates. Moisture stress during this stage may reduce photosynthetic activity and affect fruit retention and early fruit development.

Guava genotypes also differ in the duration from flowering to fruit set, indicating that this stage should be identified phenologically rather than by a fixed number of days alone (Singh *et al.,* 2020). Thus, the petal fall–fruit-set period represents an important third window for targeted foliar intervention.

Role of bioregulators in moisture-stress mitigation

Bioregulators can help plants tolerate moisture stress by improving physiological and biochemical defence mechanisms. Their effects are mainly related to better water balance, protection of photosynthetic pigments and reduction of oxidative damage. In this review, salicylic acid, melatonin and glutathione are considered important because of their reported roles in drought and other abiotic stresses. More broadly, exogenous bioregulators can influence stress signaling, antioxidant activity and photosynthetic performance under abiotic stress (Altaf *et al.,* 2023).

Salicylic acid

Salicylic acid is an important signaling molecule involved in stomatal regulation, photosynthetic protection and antioxidant defence (Hayat *et al.,* 2010; Rivas-San Vicente and Plasencia, 2011). In guava, foliar application of salicylic acid has been reported to reduce the adverse effects of water deficit on growth, gas exchange and chlorophyll-related traits (Roque *et al.,* 2025).

Therefore, salicylic acid may help maintain physiological activity when plants are exposed to limited water availability. Recent reviews also describe roles of salicylic acid in photosynthesis, osmolyte accumulation, antioxidant defence and hormonal signaling (Altaf *et al.,* 2023; Ali *et al.,* 2024).

Melatonin

Melatonin acts as both a signaling and antioxidant molecule in plants. It is associated with reactive oxygen species regulation, chlorophyll maintenance, osmotic adjustment and improved tolerance to drought and other stresses (Wang *et al.,* 2013). In fruit crops, melatonin has also been linked with fruit development, ripening and quality-related processes (Himanshu *et al.,* 2024; Fan *et al.,* 2022; Menaka *et al.,* 2024; Kashyap *et al.,* 2025). Based on evidence from other fruit crops and model systems, melatonin may have potential for use during sensitive reproductive and fruit-development stages in guava; however, its efficacy under guava-specific moisture-deficit conditions requires direct field validation. Melatonin is also involved in fruit development and ripening and interacts with stress-signaling pathways (Manzoor *et al.,* 2023; Jindal *et al.,* 2024).

Glutathione

Glutathione (GSH) is an important component of the cellular antioxidant and redox system. It helps detoxify reactive oxygen species, protects membranes and chloroplasts and supports normal metabolic activity under environmental stress (Hasanuzzaman *et al.,* 2017). GSH also participates in the ascorbate–glutathione cycle, which is an important defence mechanism against oxidative injury. Glutathione could potentially contribute to the maintenance of chlorophyll stability and photosynthetic activity under moisture deficit, although this response should be experimentally verified in guava. Collectively, these bioregulators may support physiological stability under moisture deficit through complementary signaling, antioxidant and redox-regulatory mechanisms. Recent evidence further describes GSH as a regulator of cellular redox stability and stress signaling (Rai *et al.,* 2023; Noctor *et al.,* 2024).

Phenology-guided foliar bioregulation framework

Phenology-guided foliar bioregulation links the timing of foliar application with physiologically important developmental stages of guava. Early bud development, flower-bud appearance and the petal fall–fruit-set transition represent important windows because plant water relations, assimilate demand and stress sensitivity vary during these stages.

Salicylic acid, melatonin and glutathione may provide complementary protection through stress signaling, osmotic adjustment, antioxidant defence and redox regulation. The proposed relationship between phenological stage, moisture deficit and bioregulator-mediated protection is summarized in Fig. 4.

As illustrated in Fig. 4, moisture deficit may impair plant water status, canopy cooling and photosynthetic stability, whereas appropriately timed bioregulator application may help maintain physiological functioning.

However, this framework requires field validation across bioregulator doses, cultivars and environmental conditions.

Fig.1 Major phenological stages of guava (*Psidium guajava* L.) from bud emergence to fruit ripening, with corresponding Fleckinger codes, general scale and approximate days after pruning.

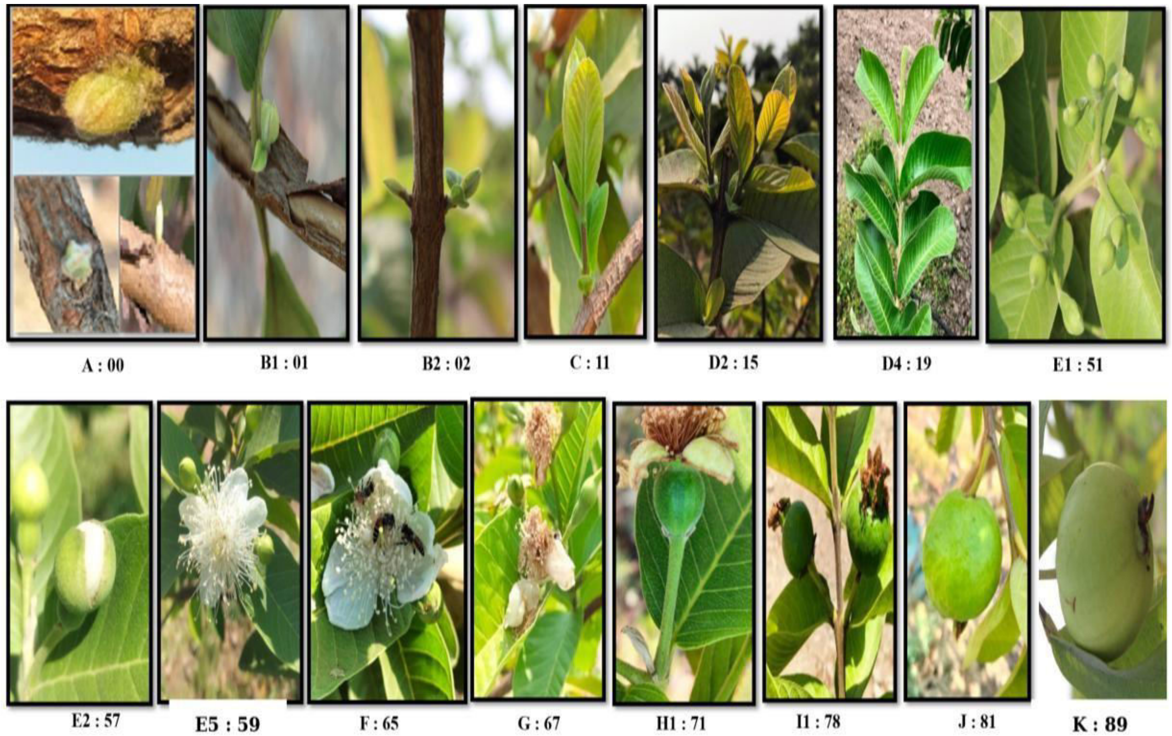

Fig.2 Phenological progression of guava following pruning and alignment of critical foliar intervention windows with major developmental transitions.

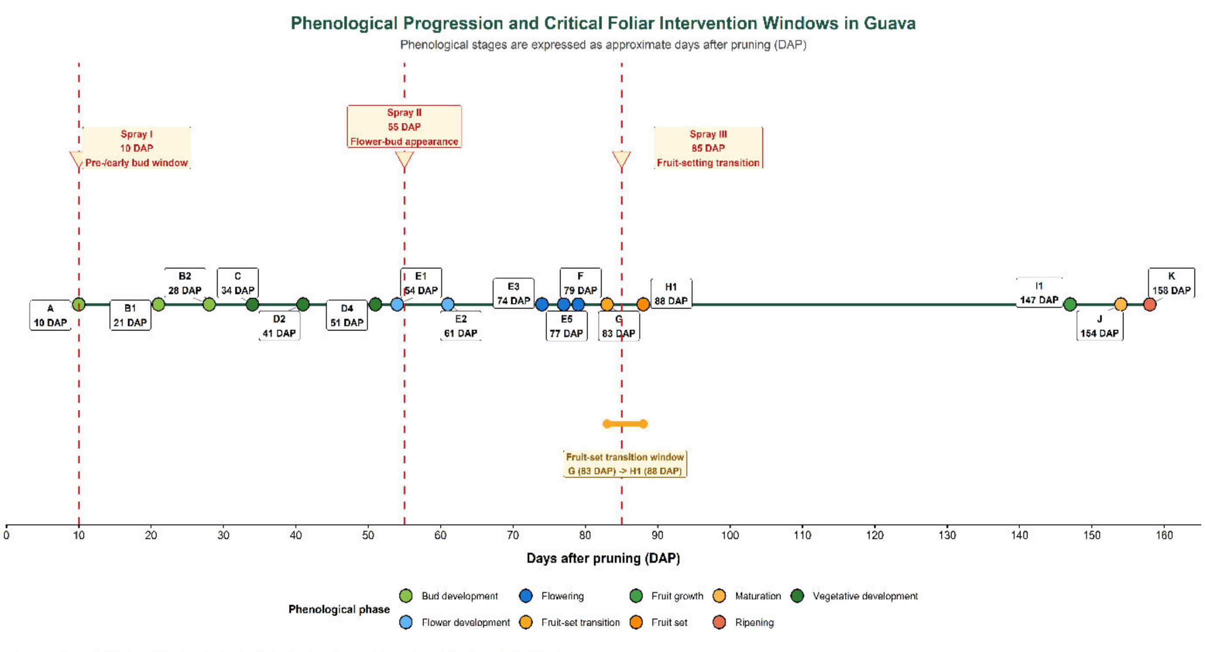

Fig.3 Conceptual assessment of the relative physiological relevance of major moisture-deficit responses across phenological stages of guava

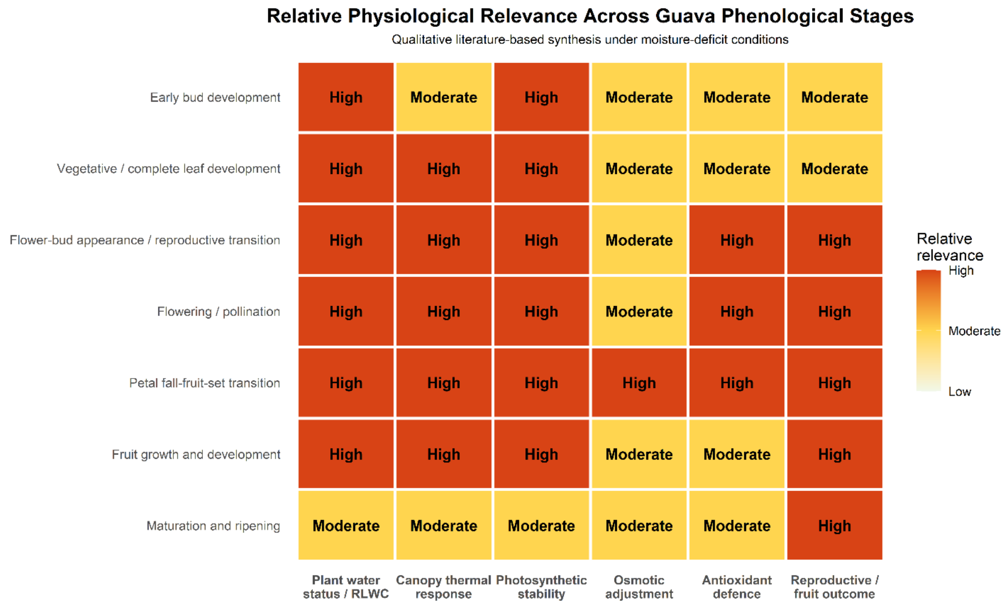

Fig.4 Proposed phenology-guided framework linking moisture-deficit responses with the protective roles of foliar bioregulators in guava.

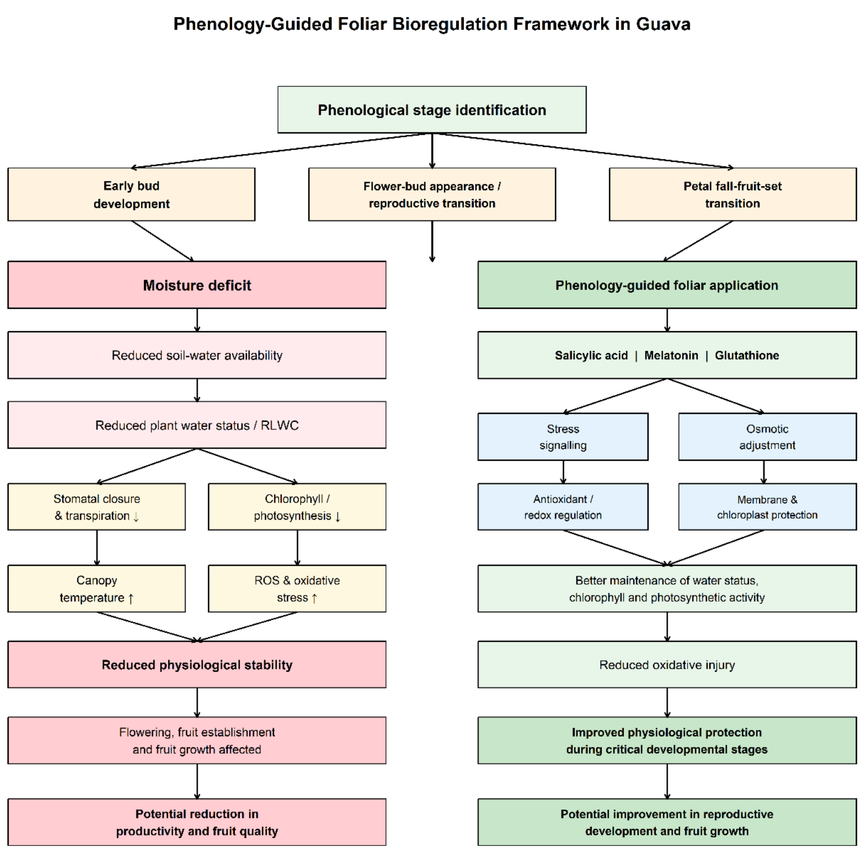

Table.1 Phenological stages of guava with Fleckinger codes, BBCH General Scale and approximate days after pruning

Sr. No.	Phenological stage	Fleckinger code	BBCH General Scale	DAP
1	Appearance of bud	A	00	10
2	Swelling of bud	B1	01	21
3	Growth of bud	B2	02	28
4	First leaves sprouting	C	11	34
5	More leaves unfolded	D2	15	41
6	Leaves completely developed	D4	19	51
7	Appearance of flower buds	E1	51	54
8	Flower bud visible	E2	57	61
9	Flower petals elongating	E3	57	74
10	Sepals fully opened	E5	59	77
11	Anthesis or 50% open flowers	F	65	79
12	Petal fall	G	67	83
13	Fruit setting	H1	71	88
14	Fruit growth (80% final size)	I1	78	147
15	Fruit colour changing	J	81	154
16	**Fruit ripening**	**K**	**89**	**158**

Table.2 Critical phenological windows for foliar intervention in guava

Critical phenological window	Approximate stage	Main importance
Bud emergence	Bud appearance and early shoot growth	**Establishment of new shoots and leaf canopy**
Reproductive transition	Flower-bud appearance	**Floral development and shift towards reproductive growth**
Fruit-set transition	**Petal fall to young fruit setting**	**Fruit establishment and retention**

Table.3 Major functions of selected bioregulators under moisture stress

Bioregulator	Major role under moisture stress	Possible physiological benefit
Salicylic acid	Stress signaling and antioxidant regulation	**Better water relations, chlorophyll protection and physiological activity**
Melatonin	Antioxidant defence and ROS regulation	**Protection of photosynthetic system and improved stress tolerance**
Glutathione	**Cellular redox and antioxidant defence**	**Protection of membranes and chloroplasts from oxidative damage**

Research gaps and future prospects

Although guava phenology, deficit irrigation and plant bioregulators have been studied individually, limited information is available on their combined role during specific developmental stages. Most studies have focused either on irrigation management, flowering behaviour or the effect of individual bioregulators, while comparatively less attention has been given to stage-specific stress sensitivity and the timing of foliar interventions. Future research should therefore focus on identifying the most sensitive phenological stages of guava under moisture deficit and validating suitable bioregulator application timings under field conditions. Greater attention is also needed on the dose × phenological stage interaction of salicylic acid, melatonin and glutathione, particularly in mature guava orchards.

Future studies should combine physiological indicators such as relative leaf water content, canopy temperature, chlorophyll stability, gas exchange and antioxidant activity with flowering, fruit set, yield, quality and water productivity. Multi-season and multi-location studies will also be important for confirming whether phenology-guided foliar application can provide consistent benefits under different cultivars and environments.

Sensor-based measurements such as canopy temperature and plant water-status monitoring may further support precision irrigation and stage-specific foliar management in guava. Non-destructive thermal imaging and canopy-temperature monitoring may further support real-time detection of crop water stress (Cho *et al.,* 2024).

In conclusion, Guava phenology provides a useful framework for understanding stage-specific responses to moisture deficit and for improving the timing of foliar interventions. Water stress can disturb plant water relations, canopy cooling, photosynthesis and antioxidant balance, particularly during sensitive reproductive stages. Salicylic acid, melatonin and glutathione may support stress tolerance through complementary physiological and biochemical mechanisms.

Among the crop stages, early bud development, flower-bud appearance and the petal fall–fruit-set transition appear particularly relevant for phenology-guided intervention. However, further multi-season field studies are required to validate suitable bioregulator × dose × phenological-stage combinations. Such an approach may contribute to improved stress tolerance, water productivity and sustainable guava production.

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Author Contributions

Sourabh S. Surve: Investigation, formal analysis, writing—original draft. Jitendrakumar H. Kadam: Validation, methodology, writing—reviewing. Machhindra G. Agale:—Formal analysis, writing—review and editing. Ganesh S. Shinde: Investigation, writing—reviewing. H. B. Thube: Resources, investigation writing—reviewing. T. S. Patil: Validation, formal analysis, writing—reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

References

Abrar MM, Sohail M, Saqib M, Akhtar J, Abbas G, Wahab HA, Mumtaz MZ, Mehmood K, Memon MS, Sun N, Xu M. Interactive salinity and water stress severely reduced the growth, stress tolerance, and physiological responses of guava (*Psidium guajava L.*). Scientific Reports. 2022; 12: 18952. https://doi.org/10.1038/s41598-022-22602-5.

Alfia MA, Vasugi C, Honnabyraiah MK, Adiga JD, Shivapriya M, Vincent L. Phenological stages of wild species and cultivated species of guava (*Psidium guajava L.*). International Journal of Pure & Applied Bioscience. 2017; 5(6): 464–474.

Ali A, Kant K, Kaur N, Gupta S, Jindal P, Gill SS, Naeem M. Salicylic acid: Homeostasis, signalling and phytohormone crosstalk in plants under environmental challenges. South African Journal of Botany. 2024; 169: 314–335.

Altaf MA, Shahid R, Lal P, Ahmad R, Zulfiqar F, Kumar A, Hayat F, Kumar R, Lal MK, Naz S, Tiwari RK. Current understanding of boosting power of salicylic acid for abiotic stress tolerance in horticultural crops. South African Journal of Botany. 2023; 163: 285–293.

Alves JE, Freitas BM. Pollination requirements of guava. Ciencia Rural. 2007; 37(5): 1281–1286. https://doi.org/10.1590/S0103-84782007000500010.

Cho SB, Soleh HM, Choi JW, Hwang WH, Lee H, Cho YS, Cho BK, Kim MS, Baek I, Kim G. Recent methods for evaluating crop water stress using AI techniques: A review. Sensors. 2024; 24(19): 6313. https://doi.org/10.3390/s24196313.

El-Buluk RE, Babiker EE, El Tinay AH. Biochemical and physical changes in fruits of four guava cultivars during growth and development. Food Chemistry. 1995; 54(3): 279–282. https://doi.org/10.1016/0308-8146(95)00047-M.

Fan S, Xiong T, Lei Q, Tan Q, Cai J, Song Z, Yang M, Chen W, Li X, Zhu X. Melatonin treatment improves postharvest preservation and resistance of guava fruit (*Psidium guajava L.*). Foods. 2022; 11(3): 262. https://doi.org/10.3390/foods11030262.

Foyer CH, Noctor G. Ascorbate and glutathione: The heart of the redox hub. Plant Physiology. 2011; 155(1): 2–18. https://doi.org/10.1104/pp.110.167569.

Galindo A, Collado-Gonzalez J, Grinan I, Corell M, Centeno A, Martin-Palomo MJ, Giron IF, Rodriguez P, Cruz ZN, Memmi H, Carbonell-Barrachina AA, Hernández F, Torrecillas A, Moriana A, Lopez-Perez D. Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agro-systems. Agricultural Water Management. 2018; 202: 311–324.

Gomasta J, Sarker BC, Haque MA, Anwari A, Mondal S, Uddin MS. Pruning techniques affect flowering, fruiting, yield and fruit biochemical traits in guava under transitory sub-tropical conditions. Heliyon. 2024; 10(9): e30064. https://doi.org/10.1016/j.heliyon.2024.e30064.

Hasanuzzaman M, Nahar K, Anee TI, Fujita M. Glutathione in plants: Biosynthesis and physiological role in environmental stress tolerance. Physiology and Molecular Biology of Plants. 2017; 23(2): 249–268.

Hayat Q, Hayat S, Irfan M, Ahmad A. Effect of exogenous salicylic acid under changing environment: A review. Environmental and Experimental Botany. 2010; 68(1): 14–25. https://doi.org/10.1016/j.envexpbot.2009.08.005.

Himanshu, Sharma S, Rana VS, Ankit, Thakur V, Kumar A, Prachi, Thakur S, Sharma N. Unlocking the sustainable role of melatonin in fruit production and stress tolerance: A review. CABI Agriculture and Bioscience. 2024; 5: 103.

Jat R, Singh VP, Ali Abed S, Al-Ansari N, Singh PK, Vishwakarma DK, Choudhary A, Al-Sadoon MK, Popat RC, Jat SK. Deficit irrigation scheduling with mulching and yield prediction of guava (*Psidium guajava L.*) in a subtropical humid region. Frontiers in Environmental Science. 2022; 10: 1044886.

Jayswal DK, Sharma DP, Dwevedi AK, Sharma TR. Pruning and integrated nutrient management for growth and yield of guava (*Psidium guajava*). The Indian Journal of Agricultural Sciences. 2019; 89(9): 1477–1481. https://doi.org/10.56093/ijas.v89i9.93493.

Jindal P, Kant K, Kaur N, Gupta S, Ali A, Naeem M. Melatonin: Discovery, biosynthesis, phytohormones crosstalk, and roles in agricultural crops under abiotic stress conditions. Environmental and Experimental Botany. 2024; 226: 105942. https://doi.org/10.1016/j.envexpbot.2024.105942.

Kashyap S, Prakash P, Barman K. Exogenous melatonin treatment delays senescence of guava fruit by modulating antioxidant activities. Applied Fruit Science. 2025; 67(5): 387. https://doi.org/10.1007/s10341-025-01622-1.

Khan FI, Akhtar S, Qamar M, Ismail T, Saeed W, Esatbeyoglu T, Jafari SM. A comprehensive review on guava: Nutritional profile, bioactive potential, and health-promoting properties of its pulp, peel, seeds, pomace and leaves. Trends in Food Science & Technology. 2025; 156: 104822.

Koti S, Ahlawat TR, Tandel BM, Patel AI, Niyaria R, Tank RV, Pandey AK, Zala VR. Variability in floral morphology, flowering behaviour and fruit set among guava (*Psidium guajava L.*) genotypes. Journal of Applied Horticulture. 2026; 28(2): 301–306. https://doi.org/10.37855/jah.2026.v28i02.47.

Lacerda CN, Lima GS, Soares LAA, Silva SS, Queiroz VF, Gheyi HR, Ferreira JTA, Almeida FS, Sousa VFO. Deficit irrigation and ascorbic acid in guava cultivation at different development stages. Ciencia Rural. 2026; 56(5): e20250078. https://doi.org/10.1590/0103-8478cr20250078.

Lakhawat SS, Sharma V, Singh TK, Patil P, Priyadevi S, Gutam S. Effects of pan evaporation-based drip irrigation levels on performance of guava grown in Udaipur and Rewa regions of India. Journal of Agrometeorology. 2024; 26(1): 69–73. https://doi.org/10.54386/jam.v26i1.2306.

Manjunath BL, Ramesha GK, Gutam S. Phenology-based irrigation management in guava orchards. Journal of Horticultural Sciences. 2024; 19(2). https://doi.org/10.24154/jhs.v19i2.2351.

Manzoor MA, Xu Y, Lv Z, Xu J, Wang Y, Sun W, Liu X, Wang L, Wang J, Liu R, Whiting MD, Jiu S, Zhang C. Melatonin: A multi-functional regulator of fruit crop development and abiotic stress response. Scientia Horticulturae. 2023; 321: 112282.

Menaka M, Asrey R, Meena NK, Vargheese E, Sethi S, Vinod BR, Ahamad S, Goswami AK. Effect of melatonin on biochemical changes, antioxidant system and oxidative membrane damage of Indian guava (cv. Barafkhana) during cold storage. South African Journal of Botany. 2024; 169: 95–108. https://doi.org/10.1016/j.sajb.2024.04.007.

Mercado-Silva E, Benito-Bautista P, García-Velasco MA. Fruit development, harvest index and ripening changes of guavas produced in central Mexico. Postharvest Biology and Technology. 1998; 13(2): 143–150. https://doi.org/10.1016/S0925-5214(98)00003-9.

Mondal K, Malhotra SP, Jain V, Singh R. Oxidative stress and antioxidant systems in guava (*Psidium guajava L.*) fruits during ripening. Physiology and Molecular Biology of Plants. 2009; 15(4): 327–334. https://doi.org/10.1007/s12298-009-0037-3.

Nithishni J, Rao V, Chinnaiyan V, Reddy BA, Hugar P. Assessment of floral phenology and pollen quality in guava (*Psidium guajava L.*) genotypes. Journal of Advances in Biology & Biotechnology. 2026; 29(1): 8–18. https://doi.org/10.9734/jabb/2026/v29i13502.

Noctor G, Mhamdi A, Chaouch S, Han Y, Neukermans J, Marquez-Garcia B, Queval G, Foyer CH. Glutathione in plants: An integrated overview. Plant, Cell & Environment. 2012; 35(2): 454–484. https://doi.org/10.1111/j.1365-3040.2011.02400.x.

Noctor G, Cohen M, Trémulot L, Châtel-Innocenti G, Van Breusegem F, Mhamdi A. Glutathione: A key modulator of plant defence and metabolism through multiple mechanisms. Journal of Experimental Botany. 2024; 75(15): 4549–4572. https://doi.org/10.1093/jxb/erae194.

Patel RK, Maiti CS, Deka BC, Deshmukh NA, Verma VK, Nath A. Physical and biochemical changes in guava (*Psidium guajava L.*) during various stages of fruit growth and development. International Journal of Agriculture, Environment and Biotechnology. 2015; 8(1): 75–82.

Rai GK, Kumar P, Choudhary SM, Singh H, Adab K, Kosser R, Magotra I, Kumar RR, Singh M, Sharma R, Corrado G, Rouphael Y. Antioxidant potential of glutathione and crosstalk with phytohormones in enhancing abiotic stress tolerance in crop plants. Plants. 2023; 12(5): 1133.

Rivas-San Vicente M, Plasencia J. Salicylic acid beyond defence: Its role in plant growth and development. Journal of Experimental Botany. 2011; 62(10): 3321–3338. https://doi.org/10.1093/jxb/err031.

Roque IA, Soares LAA, Lima VLA, Sousa VFO, Lima GS, Gheyi HR, Dantas MV, Ferreira JTA, Torres RAF, Silva STA. Foliar application of salicylic acid mitigates water deficit in guava. Revista Brasileira de Engenharia Agrícola e Ambiental. 2025; 29(5): e288437.

Sahoo J, Tarai RK, Sethy BK, Sahoo AK, Swain SC, Dash D. Flowering and fruiting behaviour of some guava genotypes under East and South East Coastal Plain Zone of Odisha, India. International Journal of Current Microbiology and Applied Sciences. 2017; 6(11): 3902–3911.

Salazar DM, Melgarejo P, Martínez R, Martínez JJ, Hernández F, Burguera M. Phenological stages of the guava tree (*Psidium guajava L.*). Scientia Horticulturae. 2006; 108(2): 157–161.

Santhoshkumar GM, Bhowmick N, Chakraborty A, Dey AN, Ghosh A, Dutta P, Deb P, Chamling N, Sherpa NT, Senjam BD. Effect of shoot pruning on growth, flowering and fruiting characteristics of different guava (*Psidium guajava L.*) cultivars. International Journal of Fruit Science. 2022; 22(1): 686–695. https://doi.org/10.1080/15538362.2022.2109094.

Selvaraj Y, Pal DK, Edward Raja M, Rawal RD. Changes in chemical composition of guava fruits during growth and development. Indian Journal of Horticulture. 1999; 56(1): 10–18.

Sharma S, Sehrawat SK, Saran PL. Comparative performance of superior guava genotypes in Northern India: Flowering and fruit set. Indian Journal of Horticulture. 2011; 68(2): 193–196.

Sharma S, Sehrawat SK, Sharma KD. Studies on time and duration of flowering, floral bud development and morphology of guava (*Psidium guajava L.*)

under semi-arid region of India. International Journal of Current Microbiology and Applied Sciences. 2017; 6(12): 4176–4186.

Sharma S, Sharma G, Srivastav M, Pal R, Singh A, Sharma S, Abrol G, Choudhary R, Kumar A. Codification and description of growth stages in guava (*Psidium guajava L.*) using the extended BBCH scale. Scientific Reports. 2026. https://doi.org/10.1038/s41598-026-64870-5.

Singh A, Reddy KS, Singh J. Phenological stages of guava-A review. International Journal of Current Microbiology and Applied Sciences. 2020; 9(12): 736–744.

Singh G, Rajan S, Pandey D, Singh AK. Effect of soil-moisture stress on water relation by plant and cropping behaviour in guava (*Psidium guajava*). The Indian Journal of Agricultural Sciences. 1997; 67(7): 303–306.

Singh VK, Ravishankar H, Singh A, Soni MK. Pruning in guava (*Psidium guajava*) and appraisal of consequent flowering phenology using modified BBCH scale. The Indian Journal of Agricultural Sciences. 2015; 85(11): 1472–1476.

Usman M, Bokhari SAM, Fatima B, Rashid B, Nadeem F, Sarwar MB, Nawaz-ul-Rehman MS, Shahid M, Ayub CM. Drought stress mitigating morphological, physiological, biochemical and molecular responses of guava (*Psidium guajava L.*) cultivars. Frontiers in Plant Science. 2022; 13: 878616.

Vadez V, Grondin A, Chenu K, Henry A, Laplaze L, Millet EJ, Carminati A. Crop traits and production under drought. Nature Reviews Earth and Environment. 2024; 5: 211–225. https://doi.org/10.1038/s43017-023-00514-w.

Wang P, Sun X, Li C, Wei Z, Liang D, Ma F. Long-term exogenous application of melatonin delays drought-induced leaf senescence in apple. Journal of Pineal Research. 2013; 54(3): 292–302. https://doi.org/10.1111/jpi.12017.

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