Mango flowering: factors involved in the natural environment and associated management techniques for commercial crops

- Review of Literature -

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Abstract: The mango (*Mangifera indica* L.) is a species of Anacardiaceae family, it has a highly appreciated fruit and is widely cultivated in tropical and subtropical regions. In this crop, initiation is the first phase of the flowering process, which is characterized by the interruption of bud dormancy, cell division and elongation, and depending on the conditions and factors involved in induction, the bud can be vegetative, reproductive, or mixed. Characteristically, the factors that influence mango flowering are those especially related to the environment (air temperature, water ratios and photoperiod) and factors related to the plant (nutritional status, photoassimilates, enzymatic activity and plant hormones). Natural flowering occurs in some regions of the world, although agronomic treats associated with the production system be adopted in most orchards. In this sense, the present review aims to elaborate a world review about the scientific literature on the mango flowering process and its associated management techniques. Therefore, this review can contribute to the sustainability of mango cultivation on a global scale through the concise description of scientific information addressed to mango growers and technical personnel of the mango industry.

Keywords: *Mangifera indica* L., natural flowering, flowering control, cultural practices

1. Introduction

In the mango tree, the initiation is the first phase for the flowering process, characterized by breaking of the dormancy of the bud, high division, and cellular elongation, and depending on the conditions and factors involved in the induction, the bud may be vegetative, reproductive, or mixed (Ramírez and Davenport, 2010). This induction depends on several factors of plant and environment.

Davenport (2007) believed in an interaction between a florigenic promoter (FP), synthesized in the leaves and translocated via phloem to the apical buds, and a vegetative promoter (VP), probably being a gibberellin or associated with the synthesis pathway of this hormone. We agree with this thought but following the actual scientific literature findings there are more plant x environment factors that affect the mango flowering success, i.e., the FP is more complex and, probably, many factors acting together and simultaneously.

In the scientific literature the factors that may act on mango flowering are described as genetic characteristics, nutritional status (Winston, 2007; Oldoni et al., 2018; Lobo et al., 2019; Tenreiro, 2020), hormonal balance (Upreti et al., 2013; Cavalcante et al., 2020; Silva et al., 2020a; Silva et al., 2021; Capelli et al., 2021), branch maturation (Cavalcante et al., 2018; Cunha et al., 2022b), accumulation of organic compounds (Oliveira et al., 2017; Lobo et al., 2019; Antara et al., 2019; Mudo et al., 2020; Silva et al., 2020b; Lopes et al., 2021), side of the plant in relation to solar incidence (Ferraz et al., 2020), phenols, amino acids and enzymes (Tiwari et al., 2018; Silva et al., 2021).

The interaction of such factors with the local climate are very important, since it is well documented especially by Ramírez and Davenport (2010) that in subtropical conditions, low temperatures determine the flowering process, but in tropical climate conditions other factors are necessary such as the age of the last vegetative flush.

Thus, it is observed that there is a complex network of responses for the process of floral differentiation to occur, but that can occur naturally in some regions that meet the climate conditions.

In this sense, through the advancement of knowledge about the theme identified in the literature, it is necessary to compile information and ideas about the flowering of the mango crop both in natural conditions and with the use of orchard management techniques that support the cultivation sustainability.

2. Factors involved in mango flowering

Mango flowering has been extensively studied and is characterized as a complex process. It is affected by different factors such as the environment (air temperature, photoperiod, and rainfall) and the plant itself (mango cultivar, nutritional status, photoassimilates, enzyme activity, and plant hormones). These processes act interdependently, but many of them can be altered to provide plants with satisfactory flowering, in terms of branch ratio, panicle emission, and flowering uniformity.

According to Léchaudel and Joas (2007), mango flowering is promoted by temperature, photoperiod, plant-inherent factors, or combinations thereof, thus it is triggered both environmentally and genetically.

Below are separately described the main results available in the scientific and technical literature about the main factors of mango flowering, defined as follows:

2.1 Environmental factors

Environmental factors involved and that interfere positively or negatively with mango flowering are air temperature, water relations, and photoperiod, with the latter having the lowest impact. Despite much information available, the effects of climatic variables have not been evaluated separately. Moreover, the varieties used and specific regional conditions make decision-making inaccurate. Thus, there is a need to specify the region, mango cultivar, and climate from which flowering information was generated.

2.1.1 Air temperature

Table 1 displays the main results contained in the scientific literature about air temperature effect on mango flowering in different climates.

Table 1. Effect of air temperature on mango flowering.

Site	Climate	Cultivar	Main results	Reference
Katherine, Australia	Tropical	Calypso	11.8 – 39.1°C (Probability of obtaining 50% flowering)	Clonan et al. (2021)
Katherine, Australia	Tropical	Kensington Pride	21.2 – 38.5°C (Probability of obtaining 50% flowering)	Clonan et al. (2021)
Katherine, Australia	Tropical	Honey Gold	16.1 – 32.7°C (Probability of obtaining 50% flowering)	Clonan et al. (2021)
Malaga, Spain	Controlled conditions	Kensington	25°C (67% pollen germination)	Pérez et al. (2019)
Malaga, Spain	Controlled conditions	Osteen	25°C (45% pollen germination)	Pérez et al. (2019)
Malaga, Spain	Controlled conditions	Kent	25°C (58% pollen germination)	Pérez et al. (2019)
Bengaluru, India	Tropical Savanna	Royal Special	14.5 – 27.9°C (ratio of hermaphrodite/ staminate flowers = 1.48	Geetha et al. (2016)
Bengaluru, India	Tropical Savanna	Arka Aruna	20.8 – 29.3°C (ratio of hermaphrodite/ staminate flowers = 0.68	Geetha et al. (2016)
Bengaluru, India	Tropical Savanna	Vellaikulamban	21.6 – 30.3°C (ratio of hermaphrodite/ staminate flowers = 2.63	Geetha et al. (2016)
Bengaluru, India	Tropical Savanna	Kensington	17.8 – 28.5°C (ratio of hermaphrodite/ staminate flowers = 1.77	Geetha et al. (2016)
Bengaluru, India	Tropical Savanna	Langra	16.0 – 28.2°C (ratio of hermaphrodite/ staminate flowers = 9.19	Geetha et al. (2016)
Bengaluru, India	Tropical Savanna	Amrapali	21.3 – 29.5°C (ratio of hermaphrodite/ staminate flowers = 2.51	Geetha et al. (2016)
Bangalore, India	Tropical Savanna	Mallika	11.40 – 27.60°C (838.00 staminate flowers and 283.45 hermaphrodite flowers per panicle)	Kumar et al. (2015)
Bangalore, India	Tropical Savanna	ArkaAnmol	11.40 – 27.60°C (1154.17 staminate flowers and 176.00 hermaphrodite flowers per panicle))	Kumar et al. (2015)
Bangalore, India	Tropical Savanna	Alphonso	14.70 – 26.80°C (827.08 staminate flowers and 98.88 hermaphrodite flowers per panicle)	Kumar et al. (2015)
Bangalore, India	Tropical Savanna	Baneshan	14.70 – 26.80°C (855.00 staminate flowers and 78.00 hermaphrodite flowers per panicle)	Kumar et al. (2015)
São Manuel, BR	Warm Temperate	Bourbon	≈13.0 – ≈25.0ºC (301.00 panicles per plant)	Silva et al. (2014)
São Manuel, BR	Warm Temperate	Haden	≈13.0 – ≈25.0ºC (301.75 panicles per plant)	Silva et al. (2014)
São Manuel, BR	Warm Temperate	Tommy Atkins	≈13.0 – ≈25.0ºC (182.00 panicles per plant)	Silva et al. (2014)
São Manuel, BR	Warm Temperate	Palmer	≈13.0 – ≈25.0ºC (150.67 panicles per plant)	Silva et al. (2014)
São Manuel, BR	Warm Temperate	Parwin	≈13.0 – ≈25.0ºC (171.20 panicles per plant)	Silva et al. (2014)
Aragua, Venezuela	Tropical Forest	Manila	≤ 20ºC for 10 days (beginning of flowering)	Avilán et al. (2003)
Queensland, Australia	Controlled conditions	Nam Dok Mai	20 – 30 °C (28% with hermaphrodite flowers/inflorescence)	Sukhvibul et al. (1999)
Queensland, Australia	Controlled conditions	Kensington	15 – 25°C (31% with hermaphrodite flowers/inflorescence)	Sukhvibul et al. (1999)
Queensland, Australia	Controlled conditions	Irwin	15 – 25°C (47.6% with hermaphrodite flowers/inflorescence)	Sukhvibul et al. (1999)
Queensland, Australia	Controlled conditions	Sensation	10 – 20°C (57.2% with hermaphrodite flowers/inflorescence)	Sukhvibul et al. (1999)

Although several factors have indirect effects on mango flowering mechanism, the main climatic variable linked to floral induction is air temperature. The relationship between floral induction and temperature is complex and intertwined with plant physiological stage of epigenetic factors, so it is important to consider each mango cultivar individually.

Under natural conditions and without proper management, exposure to low temperatures (daily minimum and maximum) is essential for floral induction. On the other hand, mango is adapted to tropical and subtropical conditions, that is, floral induction is also limited by excessively low temperatures.

In the literature, there are contrasting results about temperature effects on mango flowering. Many studies have tried to identify upper and lower limits for an optimal induction and identified variation among cultivars. In this sense, Davenport (2007), without specifying the cultivar, inferred that mango grown in subtropical regions (latitude 23°-30°), where seasonal temperature changes are substantial, flowering is induced when nighttime temperatures vary from 10-15°C. °C, thus being the preponderant factor. Pérez-Barraza et al. (2018), in a study with the mango cultivar Ataulfo, concluded that the beginning of floral bud development was stimulated at night temperatures around 15 ºC. Luo et al. (2019), in a recent literature review on the subject, observed that most studies report that mango floral induction occurs within temperature ranges between 15–19 °C during the day and 10–15 °C at night. In Australia, Clonan et al. (2020) recorded that floral induction coincided with maximum daily temperatures between 28–32 °C and minimum nocturnal temperatures below 20 °C for the varieties Calypso and Honey Gold. Finally, Yeshitela et al. (2004) found that the time of cold temperatures needed for floral initiation in mango varies with the temperature and may be from 4 days to 2 weeks for the cultivar 'Haden' and up to 35 days for 'Tommy Atkins' and 'Keitt'.

Ávilan et al. (2003) pointed out that the onset of flowering is associated with an increase in the number of accumulated days with nighttime temperatures equal to or below 20°C for 'Haden' and 'Tommy Atkins'.

Puche et al. (2012) concluded that, in the warmer periods, for 'Haden' plants, there was no relationship between days with minimum temperatures below 21º, 20º, 19º, 18º, and 17ºC, and the beginning of flowering, while in the coldest cycles this correlation was observed.

Silva et al. (2014) found different numbers of panicles per plant for the varieties Palmer, Tommy Atkins, Haden, Parwin, and Bourbon, with temperatures ranging from ≈13.0 to ≈25.0ºC (Table 1).

Huang et al. (2010) studied sexual reproduction in mangoes of the cultivar 'Tainong 1' under low temperatures (maximum diurnal temperature < 20 ºC) and compared it with "normal" temperatures (maximum diurnal ranging from 25 to 30 ºC, mean diurnal temperature > 20 °C). These authors observed that low natural temperatures resulted in low-viability pollen grains and slow pollen tube growth, hence low fertilization rates.

Lemos et al. (2018) identified that mango of the mango cultivar Ubá had a base temperature of 10 °C as a lower limit for flowering and plant development.

Pérez et al. (2019) concluded that low temperature has an effect on mango pollen viability and that there is a differential genotypic response, with a record of pollen grain germination of 67% (Kensington), 45% (Osteen), and 58% (Kent) at a controlled temperature of 25 ºC.

Without considering the varietal effect, Ravishankar et al. (2021) inferred that mango blooms during cooler months of the year, with cold temperatures especially at night. These authors indicated that night temperatures between 8 and 15 °C (46–59 °F), with daytime temperatures around 20 °C (68 °F), are required for mango flowering. Significant changes in temperature also have a positive effect on flowering. The reports by Ravishankar et al. (2021) are compatible with those of Sukhvibul et al. (2000), who inferred that the daily temperature range suitable for flowering in most cultivars is 15 to 20 °C during the day, and 10 to 15 °C at night.

Inflorescence development is affected by air temperature. Sukhvibul et al. (1999) observed that development of inflorescence did not progress when plants were kept at 15-58 ºC (day/night), and lower temperatures (20-10 ºC) delayed the onset of anthesis compared to plants grown at 25-15 ºC and 30-20°C.

Geetha et al. (2016) conducted a study in Bengaluru (India) to identify the influence of temperature on the ratio staminate: hermaphrodite flowers and found that the best results for the cultivars Langra and Kensington were achieved at minimum temperatures (15.5 to 15.7°C), while for the varieties Alphonso, Totapuri, Arka, Aruna, and Amrapaliwas it was between 16.6 and 16.8°C.

On the other hand, in the São Francisco Valley, characterized by traditionally high temperatures, there is flowering and, consequently, mango production every week of the year. This pattern may be due to the orchard management practices adopted in the region. More information of management in item 4 of this review.

2.1.2 Water relationships and photoperiod

Water relationships directly affect mango flowering in crops located in semiarid, tropical, and subtropical conditions. In irrigated crops, proper management is essential to provide uniform flowering in plants, but without compromising carbohydrate accumulations, especially in leaves, which is severely affected by excessive water stress.

Early concepts of mango irrigation indicated prolonged water stress to induce flowering in semiarid, tropical, and subtropical conditions (Whiley, 1993; Mostert and Hoffman, 1996; Bally et al., 2000). Additionally, the National Department of Agriculture of South Africa (2000), cited by Lobo & Sidhu (2017), stated that the soil should be dry for two or three months before the flowering phase in order to promote good flower formation.

Water stress at the flowering stage is advantageous for mangos under natural conditions (Laxman et al., 2016). Under tropical conditions, drought not only induces flowering, but also accelerates it and prevents vegetative flushing, giving more time for floral stimulation to accumulate.

When temperature and rainfall conditions are congruent, Davenport (2000; 2003) inferred that reproductive flows usually occur after long periods of branch rest, often after a mild drought period or during inductive cold temperatures. According to Ramírez and Davenport (2010), water stress prevents emission of new shoots and keeps the plants at rest until leaf age increases and hence flowering.

Silva et al. (2014) recorded the highest numbers of panicles per plant in months by little or no rainfall associated with lower temperatures, reaching 182, 301, and 150 panicles per plant for the varieties Tommy Atkins, Haden, and Palmer, respectively.

Carr (2014) reviewed the literature on water relationships and irrigation needs in mangoes and observed that in low-latitude tropics areas, flower buds are initiated after a drought period (six to 12 weeks), which ends after rain events or irrigation. In Malaysia, Talib et al. (2020) identified that the absence of rainfall for 60 days induced mango flowering.

In mango cultivar Kensington Pride, Bally at al. (2000) observed that irrigation suspension when the first flow was started until 70% of inflorescences emitted increased the number of terminal branches with flowers by 20.5%.

Souza et al. (2016) noted that water demands of the cultivar Tommy Atkins vary with the phenological phases, with an average daily consumption of 3.8 mm at flowering, 4.25 mm at physiological fruit-drop stage, 3.56 mm at fruit formation, and 3.0 mm at fruit maturation. During the entire production cycle, consumption varied from 403 to 420 mm.

In agreement with Schaffer et al. (1994), Laxman et al. (2016) observed that drought anticipates flowering compared to plants under normal growing conditions and attributed such a response to vegetative inhibition, thus increasing time for floral stimulus accumulation.

Halder & Hasan (2020) recommended soil moisture stress (-75 kPa or even less) before mango flowering initiation to promote a uniform flowering. However, soil moisture stress can complement low temperature requirements, depending on the mango cultivar, and thus stimulate flowering. A proper water management during pre-flowering is important, because when orchards are on light soils, flowering can be more abundant even at high temperatures, as these soils can reduce their moisture levels quickly.

Thus, it is important to highlight that water stress itself is not a preponderant factor for mango flowering, but as one of the factors that influence and can limit a uniform flowering depending on the soil and climate conditions, as well as the agronomic management adopted in the orchard.

Table 2 also shows other relevant and current results on the effects of water relations on mango flowering in different locations and for different varieties.

Table 2. Effect of water relations on mango flowering.

Site	Climate	Cultivar	Main results	Reference
Utan Aji, Malaysia	Tropical	Harumanis	Absence of rainfall for 60 days induced flowering	Talib et al. (2020)
Casa Nova, Brazil	Tropical semi-arid	Palmer	25% reduction in irrigation depth before induction	Cavalcante et al. (2018)
Pará, Brazil	Tropical humid	‘Tommy Atkins’	Average daily consumption of 3.8 mm at flowering	Souza et al. (2016)
Bangalore, India	Tropical Savanna	‘Mallika’	5 mm per day (838.00 staminate flowers and 283.45 hermaphrodite flowers per panicle)	Kumar et al. (2015)
Bangalore, India	Tropical Savanna	‘ArkaAnmol’	1.44 mm per day (1154.17 staminate flowers and 176.00 hermaphrodite flowers per panicle)	Kumar et al. (2015)
Bangalore, India	Tropical Savanna	‘Alphonso’	3.10 mm per day (827.08 staminate flowers and 98.88 hermaphrodite flowers per panicle)	Kumar et al. (2015)
Bangalore, India	Tropical Savanna	‘Baneshan’	3.00 mm per day (855.00 staminate flowers and 78.00 hermaphrodite flowers per panicle)	Kumar et al. (2015)
Darwin, Australia	Tropical Savanna	‘Kensington Pride’	0, 13, 25, and 50 mm per week before flowering promoted 23.9, 27.9, 28.8, and 13.9% flowering, respectively	Bithell et al. (2013)
Queensland, Australia	Tropical dry	‘Kensington Pride’	Water stress increased number of flowered shoots by 20.5%	Bally et al. (2000)

In fact, the effect of water relations (e.g., water depth reduction) before induction of mango flowering is dependent on the air temperature, on the rootstock used for seedling propagation, and on the mango cultivar cultivated.

Conversely, Ramirez and Davenport (2010) stated that drought stress itself does not induce flowering in mango trees, but the age of the last vegetative flush impacted by stress duration. This is because water stress prevents shoot initiation and maintains trees at rest until age accumulation in leaves takes place and trees flower due to the age-dependent reduction of the vegetative promoter. Such theory, although coherent, must consider that both factors are important since younger growth flushes hardly provide suitable conditions for flowering. Contrastingly, older growth flushes also need stimulus for panicle emission, that is, a set of factors is required for flowering in mango trees and not only isolated conditions, whether environmental or plant-related ones.

Photoperiod is not a climatic parameter with a great effect on induction of flowering in mango trees, regardless of the cultivation site. This is because little is known about its contribution to the process. Furthermore, according to Santos-Villalobos et al. (2013), mango is a non-photoperiodic tree, that is, it does not depend on photoperiod to induce flowering. This factor, however, cannot be disregarded in mango flowering, as inflorescences are normally emitted on the outer edges of plant canopy or in branches more exposed to light. Therefore, access to sunlight is relevant, especially for a uniform flowering and hence number of panicles per plant.

In this context, Núñez-Elisea and Davenport (1995) concluded that instead of a short photoperiod, colder temperatures cause floral induction, whereas warmer temperatures inhibit flowering rather than long photoperiods. Santos-Villalobos et al. (2013) evaluated Ataulfo mangoes in Mexico and observed that the flowering induction period coincided with a stable period of minimum illuminance and photoperiod, around 5,500 lux and 10.5 light hours, respectively, during which 746 ± 97 flowers were emitted.

Table 3 shows some literature reports about photoperiod effects on mango flowering for different sites and plant varieties.

Table 3. Photoperiod effect on mango flowering.

Site	Climate	Cultivar	Main results	Reference
Tapachula. Chahuites, Apatzingán, Mexico	Tropical with dry season	Ataulfo	At flowering induction, illuminance and photoperiod were at least of about 5,500 lux and 10.5 light hours. About 746 ± 97 flowers were emitted	Santos-Villalobos et al. (2013)
Bangalore, India	Tropical Savanna	Totapuri (Young plants)	8h light + 16h dark (86% flowering, 5.7 panicles per plant) 11h light + 13h dark (100% flowering, 9.7 panicles per plant) 16h light + 8h dark (100% flowering, 8.9 panicles per plant)	Murti & Upreti (1998)
Bangalore, India	Tropical Savanna	Langra (Young plants)	8h light + 16h dark (33% flowering, 0.7 panicles per plant) 11h light + 13h dark (40% flowering, 1.0 panicles per plant) 16h light + 8h dark (20% flowering, 0.6 panicles per plant)	Murti & Upreti (1998)
Bangalore, India	Tropical Savanna	Neelum (Young plants)	8h light + 16h dark (100% flowering, 8.9 panicles per plant) 11h light + 13h dark (100% flowering, 13.6 panicles per plant) 16h light + 8h dark (100% flowering, 12.7 panicles per plant)	Murti & Upreti (1998)
Bangalore, India	Tropical Savanna	Rumani (Young plants)	8h light + 16h dark (75% flowering, 8.5 panicles per plant) 11h light + 13h dark (100% flowering, 12.8 panicles per plant) 16h light + 8h dark (100% flowering, 16.6 panicles per plant)	Murti & Upreti (1998)

2.2 Plant-related factors

2.2.1 Nutritional status

Nutritional status of mango trees is another important factor in flowering, especially nutrients with specific functions in the inductive process. Yet, the well-documented effect of nitrogen cannot be disregarded, which, in this review, will be updated according to information available in the literature and professional/scientific experience about the crop.

Table 4 shows a summary of the main results from the literature review. These findings correlate nutritional status with flowering in mango trees. Most of them have tried to correlate nutritional status with fruit production or productivity, and not with flowering. These, however, do not necessarily reflect the reality, as nutrition effects on the flowering are immediate given the proximity of the event, while the respective effects on productivity are still dependent on all management performed until fruit harvest.

Table 4. Effect of nutritional status on mango flowering.

Site	Climate	Cultivar	Main results	Reference

Petrolina, BR	Tropical semiarid	'Tommy Atkins'	Average N of 16.80 g kg^{-1} in induction without deleterious effects on flowering and productivity	Cunha et al. (2022a) e Cunha (2019)
Petrolina, BR	Tropical semiarid	'Tommy Atkins'	Leaf Ca content between 15.97 and 20.49 g kg^{-1}, with flowering between 13.58% and 29.33% of the available branches in the plant	Tenreiro (2020)
Casa Nova, BR	Tropical semiarid	'Tommy Atkins'	21.11 g kg^{-1} **N**, 1.54 g kg^{-1} **P**, 12.75 g kg^{-1} **K**, 8.86 g kg^{-1} **Ca**, 2.01 g kg^{-1} **Mg**, 138.57 mg kg^{-1} **Mn**, 31.02 mg kg^{-1} **Fe**, 76.11 mg kg^{-1} **Zn**, 98.70 mg kg^{-1} **B** (5.6 reproductive shoots per m^{2} canopy, 51.58% hermaphrodite flowers)	Mudo et al. (2020)
Petrolina, BR	Tropical semiarid	'Kent'	Leaf N contents between 13.49 (2016) and 17.78 g kg^{-1} (2017) in induction without damage to flowering	Lobo et al. (2019)
Petrolina, BR	Tropical semiarid	'Kent' 2016 cycle	At full flowering: 7.95 g kg^{-1} **N**, 1.50 g kg^{-1} **P**, 3.43 g kg^{-1} **K**, 15.46 g kg^{-1} **Ca**, 0.74 g kg^{-1} **Mg**, 99.72 mg kg^{-1} **Mn**, 21.10 mg kg^{-1} **Fe**, 12.70 mg kg^{-1} **Zn**, 29.87 mg kg^{-1} **B** (100.56 panicles per plant and 1.13 fruits per panicle)	Lobo et al. (2019)
Petrolina, BR	Tropical semiarid	'Kent' 2017 cycle	At full flowering: 14.84 g kg^{-1} **N**, 2.12 g kg^{-1} **P**, 4.80 g kg^{-1} **K**, 12.90 g kg^{-1} **Ca**, 1.01 g kg^{-1} **Mg**, 117.98 mg kg^{-1} **Mn**, 25.40 mg kg^{-1} **Fe**, 12.88 mg kg^{-1} **Zn**, 181.12 mg kg^{-1} **B** (56.76 panicles per plant and 1.37 fruits per panicle)	Lobo et al. (2019)
Bhubaneswar, India	Hot and humid tropical	Arka Neelachal Kesari	4.6 g kg^{-1} **N**, 1.0 g kg^{-1} **P**, 7.1 g kg^{-1} **K**, 43.2 g kg^{-1} **Ca**, 4.3 g kg^{-1} **Mg**, 9.54 mg kg^{-1} **Cu**, 21.24 mg kg^{-1} **Zn** (92.7% flowering)	Kishore et al. (2019)
Casa Nova, BR	Tropical semiarid	Palmer	Negative effect when leaf N > 18 g kg-1 during induction	Cavalcante et al. (2018)
Petrolina, BR	Tropical semiarid	'Palmer'	Leaf B contents between 216 and 311mg kg^{-1} promoted no damage to flowering and crop productivity.	Oldoni et al. (2018)
India	Hot and humid tropical	Ten varieties	High foliar N levels at flowering promoted greater emission of hermaphrodite flowers	Kumar et al. (2014)
Minia, Egypt	Arid	'Hindy Bisinara'	14.1 g kg^{-1} **N**, 1.1 g kg^{-1} **P**, 5.9 g kg^{-1} **K**, 2.5 g kg^{-1} **Mg**, 166.1 mg kg^{-1} **Fe**, 24.1 mg kg^{-1} **Zn**** (96 panicles per plant, 550 flowers per panicle (0.22% fruit retention)	Ibrahim et al. (2007)
Minia, Egypt	Arid	'Hindy Bisinara'	15.5 g kg^{-1} **N**, 1.2 g kg^{-1} **P**, 6.2 g kg^{-1} **K**, 2.0 g kg^{-1} **Mg**, 171.0 mg kg^{-1} **Fe**, 25.0 mg kg^{-1} **Zn**** (98 panicles per plant, 530 flowers per panicle (0.24% fruit retention)	Ibrahim et al. (2007)
Australia	Subtropical	Keitt	These authors recommend varying N levels between 10 and 12 g kg^{-1} during the cycle, with a lower limit during flowering	Winston (2007)

**Data with converted units of measure, without changing the actual values.

Thus, the results in Table 4 highlight cultivar- and environment-specific effects on mango flowering, rejecting the generalized idea of nutritional status effects.

Broadly speaking, nutritional status of mango trees is fundamental for a satisfactory flowering. Among all nutrients, some have primary functions during that phase, therefore, their leaf concentrations must be monitored and maintained. The greatest impacts on mango flowering can be observed in case of excess nitrogen or calcium and boron deficiencies, which directly compromise the process.

Nitrogen content in mango leaves has been reported as a critical parameter for flowering onset (Davenport et al., 2003; Avilán, 2008). Elevated levels of this nutrient during floral induction have deleterious effects on panicle emission or mixed sprouting. Such high levels are unwanted because they increase vegetative development to the detriment of flowering (Ramírez and Davenport, 2010). However, there are still older findings in the literature that indicate higher critical (negative) nitrogen contents and therefore should be updated to reflect recent scientific evidence.

According to Davenport (2003), nitrogen levels during floral induction in mango leaves should vary between 11 and 14 g kg^{-1}. As for Ávilan (2008), to suppress frequent vegetative flushes and induce flowering, N levels should reach 14 g kg^{-1} (1.4%). Oliveira et al. (nd) reported that N levels between 7.42 to 14.28 g kg^{-1} (11.81 g kg^{-1} on average) in 'Palmer' mango leaves did not compromise flowering. Cavalcante et al. (2018) reported that foliar N concentrations during 'Palmer' mango flowering only had a negative effect when they reached an average of 18.11 g kg^{-1} under semi-arid conditions. In 'Kent' mangoes, Lobo et al. (2019) reported that leaf N levels during flowering induction between 13.49 (2017) and 17.78 g kg^{-1} (2016) provided 1.13 (2016) and 1.37 (2017) fruits per panicle and production of 102 (2016) and 78 (2017) fruits per plant. Mudo et al. (2020) observed that Tommy Atkins mango trees grown under a semi-arid tropical climate had an average nitrogen level of 21.11 g kg^{-1} during branch maturation, with 5.6 reproductive shoots per m2 canopy and 51.58% hermaphrodite flowers. Also, for Tommy Atkins mangoes grown in a semi-arid tropical climate, Lopes et al. (2021) recorded an average N content of 12.20 g kg^{-1} with no deleterious effects on flowering and a minimum yield of 15.6 t ha^{-1}. Finally, Cunha (2019) and Cunha et al. (2022a) recorded leaf N levels during flowering of Tommy Atkins mangoes of 16.80 g kg^{-1}, without negative effects on production.

El-Hoseiny et al. (2020), in a study with the mango cultivar 'Zebda' in Egypt, recorded leaf N levels ranging from 14.30 g kg^{-1} to 18.30 g kg^{-1}, which promoted a number of panicles per plant of 157 and 338 respectively.

During full bloom, Lobo et al. (2019) identified leaf N contents ranging from 7.95 g kg^{-1} to 14.84 g kg^{-1} N that provided, respectively, emissions of 100.56 panicles per plant (1.13 fruits per panicle) and 56.76 panicles per plant (1.37 fruits per panicle).

It is noteworthy that N is one of the most absorbed nutrients and has a direct effect on the partition of photoassimilates between vegetative and reproductive parts. This role helps modify plant physiology and morphology as it is related to photosynthesis, root growth, ionic absorption of nutrients, and cell development (Queiroga et al., 2007). At floral induction, N contents must be within a mean lower limit for a supply to encourage reproductive rather than vegetative growth.

During the vegetative phase, there is also a correlation of nitrogen values with mango fruit production. Silva et al. (2014) evaluated foliar macronutrients in mango trees of different ages during the vegetative phase in the São Francisco Valley and found N values ranging from 12.61 g kg^{-1} to 17.95 g kg^{-1}. Quaggio (1996) compiled literature data and observed adequate nitrogen values between 12 to 14 g kg^{-1} for mangoes. Based on a nutritional analysis of high-yield Kent, Keitt, and Tommy Atkins mangoes, Rezende (2021) observed a higher range between 13.4 to 16.7 g kg^{-1}. Kumar et al. (2015) observed a strong correlation between leaf nitrogen levels during the vegetative phase and fruit production of 'Dashehari' mango trees. Otherwise, for 'Palmer' mango, Oliveira et al. (nd) did not identify a significant correlation between foliar nitrogen concentrations and production.

Nitrogen is normally more required by plants for the synthesis of structural compounds such as amino acids, nucleic acids, lipids, and chlorophylls (Kusano et al., 2011) although increased availability interferes with assimilation and partitioning of photoassimilates in plants (Liu et al., 2018). Moreover, in mango, nitrogen promotes regular emission of shoots, which, when they reach maturity, will result in branches responsible for flowering and fruiting (Silva et al., 2002). However, it is important to highlight that excess N during pre-flowering can also negatively affect productivity through emission of a lower proportion of panicles rather than vegetative shoots (Litz, 2009).

Another important nutrient for flowering is calcium, which is essential in all new growth points of mango trees, including roots, root hairs, leaves, flowers, and pollen tube emission (Winston, 2007). Tenreiro (2020) recorded that foliar calcium contents ranging between 15.97 and 20.49 g kg^{-1} promoted an average flowering rate between 13.58% and 29.33% of the branches available in the plant.

Furthermore, boron plays a vital role in hormonal movement, flowering, activation of salt absorption, fruiting, pollen germination, and pollen-tube growth (Khan et al., 2021). Among micronutrients, this element (B) has great importance in fertilization, and production of mango seeds and fruits given its role in pollen grain germination and pollen tube growth (Saran and Kumar, 2011). Therefore, the lack of B results in poor flowering and hence inefficient pollination, in addition to reduced fruit sizes. Deficiency symptoms are most visible during flowering, with affected plants producing deformed inflorescences. In this sense, Muengkaew et al. (2017) assessed foliar Ca and B applications and reported pollen germination rates from about 25% (control) to 60% after applying 3 ml L^{-1} culture medium containing 40% calcium (Ca $(NO_3)2.4H_2O$) and 0.3% boron (H_3BO_3).

According to the literature, there is no consensus on ideal B contents, and sufficiency ranges are incongruous and poorly interrelated with each other. For example, Winston (2007) recommended foliar B levels between 1 and 2 mg kg^{-1}, which is inconceivable for Brazilian semiarid conditions. On the other hand, Mudo et al. (2020) found 51.58% of hermaphrodite flowers with a mean B content of 98.70 mg kg^{-1} in Tommy Atkins mangoes. As for Lobo et al. (2019), a leaf B content of 29.87 mg kg^{-1} provided 100.56 panicles per plant in Kent mango. Finally, Oldoni et al. (2018) studied boron fertilization in 'Palmer' mango under tropical semi-arid conditions in Brazil and found that flowering and productivity were not affected for leaf contents between 216 and 311mg kg^{-1}.

2.2.2 Photoassimilates and enzyme activity

According to Davenport (2009), photoassimilates may be necessary for floral induction, and it is currently believed that they not only are but play an important role in this process. In 'Palmer' mangoes, leaf concentrations of total soluble carbohydrates peak during branch maturation, decreasing around the time of floral induction (Cavalcante et al., 2018). For these authors, this reduction can vary from 154 to 346% according to environmental conditions and branch maturation strategies adopted. Similar data were also reported by Urban et al. (2006) in a study on seasonal effects on leaf nitrogen partition and photosynthetic water-use efficiency in mango plants. These results also corroborate those of Lopes et al. (2021), who evaluated the mango cultivar 'Tommy Atkins' and recorded a 77.05% reduction in total soluble carbohydrates in leaves from early flowering to full bloom; likewise, Lobo et al. (2019) evaluated ‘Kent’ mango grown in a semi-arid environment and observed an average reduction of 21.83% during the same phase.

For Prasad et al. (2014), high levels of carbohydrates are observed in the pre-flowering phase due to intense activity of hydrolytic enzymes and mobilization of leaf metabolites for panicle formation, followed by a decrease in full flowering. Pongsomboon et al. (1997) stated that mango flowering is induced by high carbohydrate levels. Likewise, Antara et al. (2019) claimed that in a normal flowering year, the mango cultivar ‘Amparali’ can maintain carbohydrate contents above the limit for optimal source-to-sink transfers; conversely, the cultivar Dashehari, under the same conditions, cannot maintain high carbohydrate levels and hence has its flowering impaired. Diversely, carbohydrate concentrations in in branches with no leaves were lower than those in leaves, regardless of time in the maturation phase of branches, and showed a distribution similar to that recorded for leaves, that is, a drastic decrease when approaching floral induction (Cavalcante et al., 2018).

Davenport (2009) inferred that if a florigen-promoting gene product is synthesized in small amounts in leaves, it must be able to move to these buds via the phloem. This statement can and must be correct but does not necessarily refer to total soluble carbohydrate synthesis in mangoes. It is based on observations by Cavalcante et al. (2018), who recorded extremely higher mean total soluble carbohydrate levels in plants without branch maturation, as these plants showed very poor or null flowering. Therefore, for mangoes, high carbohydrate concentrations, specifically in buds, is not the key to a good flowering and fruit production or that, in parallel, the levels demanded are lower than those observed for other organs.

Notably, sugar transport from sources to sinks is one of the main determinants of plant growth. This process depends on an efficient and controlled distribution of sucrose (and other sugars such as raffinose and polyols) to plant organs via phloem. However, this phloem transport system can be affected by many environmental factors, thus altering the source and sink relationships (Lemoine et al., 2013). Due to the requirement for high solute concentrations to motivate phloem flow, a low florigenic promoter (FP) concentration could not cause fluid movement through sieve tubes on its own. The much higher concentrations of photoassimilated sugars carried by water loading into the phloem in leaves passively transport FP towards numerous sinks, including respiratory buds, where they are used for floral induction.

Biomass production in mango, including that required for flowering, results from the conversion of radiant energy into carbohydrates through photosynthesis. In this sense, Mouco et al. (2010) highlighted that the amount of carbon fixed in this process and consequent distribution to different plant organs are important for the events occurring during the crop phenological cycle. At the same time, environmental variations influence photosynthetic activity and hence define plant performance.

Although there is little consensus regarding the roles of carbohydrates and N in mango flowering, starch is a carbohydrate important for mango flowering. This can be evidenced by its accumulations during long canopy rest periods before flowering. Gamboa-Porras & Marín-Méndez (2012) aimed to determine seasonal changes in starch contents of mango trees and relate them to plant phenological patterns and production for the varieties ‘Tommy Atkins’ and ‘Keitt’. They observed that both genotypes showed the same trend, but the latter had higher contents in all samples. Low concentrations were observed in post-harvest periods, and maximum values in pre-flowering. In this sense, the importance of starch for flowering can be inferred. Moreover, woody plants accumulate reserves during pre-flowering, which are later consumed for flower and fruit development. Finally, Capelli et al. (2021) studied the varieties ‘Cogshall’ and ‘José’ in Saint-Pierre (França) and also identified starch accumulations during the vegetative stage that decreased with the onset of flowering.

In fact, it is important to highlight that during the vegetative cycle mango shows significant variations in carbohydrate levels. This is confirmed because these values are greatly influenced by climatic conditions, management, cultivar, and even the phenological stage of the crop itself (Antara et al., 2019; Lopes et al., 2021).

Table 5 presents some results on the importance of carbohydrates and nitrate reductase enzyme activity for mango flowering.

Table 5. Effect of accumulation of total soluble carbohydrates, starch, and nitrate reductase activity on mango flowering.

Site	Climate	Cultivar	Main results	Reference
Casa Nova, BR	Tropical semiarid	Tommy Atkins	120 µmol mg g^{-1} MF branches at full bloom (26 t ha^{-1}) 70 µmol mg g^{-1} MF branches at full bloom (17 t ha^{-1})	Lopes et al. (2021)
Saint-Pierre, FR	Oceanic	Cogshall and José	Increased starch concentrations at vegetative and pre-flowering phases with reduction at flowering	Capelli et al. (2021)
Petrolina, BR	Tropical semiarid	Palmer	Increase in nitrate reductase activity by about 78% from before to after flowering induction	Santos et al. (2021)

Petrolina, BR	Tropical semiarid	Palmer	≅200 μmol g^{-1} FM in leaves during pre-flowering promoting a uniform flowering	Cavalcante et al. (2020)
Petrolina, BR	Tropical semiarid	Kent 2016 cycle	45.81 mg g^{-1} MF in leaves during pre-flowering and 37.81 mg g^{-1} MF at full bloom (100.56 panicles per plant and 1.13 fruits per panicle)	Lobo et al. (2019)
Petrolina, BR	Tropical semiarid	Kent 2017 cycle	38.56 mg g^{-1} MF in leaves during pre-flowering and 42.59 mg g^{-1} MF at full bloom (56.76 panicles per plant and 1.37 fruits per panicle)	Lobo et al. (2019)
India	Tropical Savanna	Dashehari and Amparali	Carbohydrates (high) comprise one of the inductive factors for mango flowering	Antara et al. (2019)
Casa Nova, BR	Tropical semiarid	Palmer	High levels of carbohydrates in leaves (around 120 mg g^{-1} MF) at the end of shoot maturation (floral induction) is crucial for obtaining high yields.	Cavalcante et al. (2018)
Petrolina, BR	Tropical semiarid	Palmer	250.20 to 396.60 mg g^{-1} MF in leaves at full bloom (1.07 fruits per panicle and production of 105.98 kg per plant).	Oliveira et al. (2017)

MF = fresh mass

Among the enzymes with potential effects on mango flowering, nitrate reductase stands out. It plays a major role in nitrogen (N) metabolism and assimilation, catalyzing the reduction of nitrate (NO_3^-) to nitrite (NO_2^-) and regulating plant responses to N deficiency (Andrews et al., 2013; Kaur et al., 2015). Several factors regulate nitrate reductase activity (NRA) such as nitrate and potassium applications, which induce it in mango trees in response to potassium nitrate (KNO_3) application (Coutinho et al., 2016; Anusuya et al., 2018).

Santos et al. (2021) evaluated the mango cultivar ‘Palmer’ and observed that immediately before floral induction with potassium nitrate, nitrate reductase had greater activity in roots, statistically differing from first- and second-flush leaves, which did not differ from each other. After induction with KNO_3 foliar application in mangoes, NRA decreased in roots and equaled that in first-flush leaves, but increased in second-flush ones, which become the main site of NO_3^- reduction. In this sense, plants can modulate NRA after application of nitrate salts (Taiz et al., 2017), as this enzyme is induced by its substrate (Martuscello et al., 2016). This may explain the higher activity in second-flush leaves than in roots after spraying.

For Konishi and Yanagisawa (2011), NR gene expression is rapidly stimulated in several plants when in the presence of NO_3^-. Santos et al. (2021) observed that second-flush leaves are the main NRA sites, which can be modulated by application of exogenous nitrate via foliar or fertigation at different phenological phases in mango crops. These authors recorded an increase in NRA from about 0.09 μmol NO_2 fresh $mass^{-1}$ h^{-1} (before induction with potassium nitrate) to about 0.16 μmol NO_2 fresh $mass^{-1}$ h^{-1} (after induction with potassium nitrate). In short, KNO_3 induced NRA, a key enzyme in nitrate assimilation pathway for amino acid synthesis, in particular methionine (Anusuya et al., 2018), and this amino acid, in turn, aids in mango flowering as a precursor of ethylene (Sudha et al., 2012). In conclusion, that is why the NRA is lower in the vegetative phase than in the reproductive phase.

When soil water is available at flowering induction, reverse xylem flow is maintained and presumably prevent xylem upward movement of shoot initiating hormones (cytokinins) that are synthesized in root tips (Mok, 1994), accumulating therein and negatively interfering with flowering.

2.2.3 Plant hormones

There is extensive literature available regarding effects of plant hormones on mango flowering. Some studies have assessed variations in their levels during the phenological cycle, enabling or not plant flowering (Chacko, 1986; Núñez-Elisea and Davenport, 1998; Davenport, 2000; Beveridge et al., 2003; Naphrom et al., 2004; Protacio et al., 2009; Upreti et al., 2013; Prasad et al., 2014; Burondkar et al., 2016; Antara et al., 2019; Cavalcante et al., 2020; Silva et al., 2021; Capelli et al., 2021; Bajpai et al., 2021). Find in Table 6 a resume of the main results of the relationship between plant hormones and mango flowering.

Table 6. Effect of hormones on mango flowering.

Local	Climate	Cultivar	Main results	Reference
Saint-Pierre, France	Humid continental	Cogshall and José	Auxin and abscisic acid concentrations were higher in flower buds compared to quiescent shoots	Capelli et al. (2021)
Cabrobó, Brazil	Tropical semiarid	Keitt	Low gibberellin levels promoted flowering between 70 and 99% in mango plants	Silva et al. (2021)
Petrolina, Brazil	Tropical semiarid	Palmer	Decreasing levels of gibberellin are associated with increased carbohydrates and mango flowering	Cavalcante et al. (2020)
India	Tropical humid	Dashehari and Amparali		Antara et al. (2019)
India	Tropical humid	Alphonso	Mean riboside zeatin values increased by 241% in buds from 15 days before dormancy breaking Mean abscisic acid values increased by 32.5% in buds from 15 days before dormancy breaking	Burondkar et al. (2016)
Bangalore	Tropical Savanna	Totapuri	In paclobutrazol untreated trees, ABA content was from 85.7 to 106.3 ng g^{-1} and from 52.3 to 65.5 ng g^{-1} in shoots and leaves from 30 days before to budding, respectively	Upreti et al. (2013)
Calatagan	Monsoon	Carabao	In paclobutrazol untreated trees, GA3 content reduced from 395.55 to 136.63 from 30 days before flowering to budding Decreasing levels of gibberellin are associated with periods of lower water availability. Reduction of 750 μg^{-1} MF to undetectable levels of gibberellin from 6 months prior to flowering	Protacio et al. (2009)

There is difficulty in isolating and interpreting the effects of hormones on the flowering of any fruit plant, given the interference of environmental factors. For Luo et al. (2019), low temperatures regulate hormone content during floral induction in mango trees.

According to the literature, mango flowering-related hormones are gibberellin, cytokinin, auxin, abscisic acid, and ethylene. Gibberellins (GAs) are flowering inhibitors of mango and other fruits. They reduce floral induction after a continuous reduction in their levels in growing buds (Upreti et al., 2013; Prasad et al., 2014; Sandip et al., 2015; Burondkar et al., 2016; Antara et al., 2019; Cavalcante et al., 2020; Silva et al., 2021). However, not all GAs act in differentiating flower buds (Upreti et al., 2013; Cavalcante et al., 2020). While a GA1 decline prepare buds for floral differentiation, GA3, GA4, and GA7 reductions act on floral bud initiation. It is noteworthy that the plant organ in which GAs must be at low levels for floral induction is the bud and not leaves. Thereby, higher levels of GAs increase vegetative growth and inhibit mango floral induction (Núñez-Elisea and Davenport, 1998; Davenport, 2000). Under high temperatures, GA3 treatment increases production of vegetative shoots, but under low temperatures it does not produce vegetative shoots and delays the onset of inflorescences (Núñez-Elisea and Davenport, 1998). These results indicated that GA3 prevents initiation of reproductive shoots rather than inhibiting floral induction in mango. Therefore, increases in gibberellins may regulate other hormones to inhibit flowering (Sandip et al., 2015).

Cytokinins (CKs) also have effects on flowering, but in an opposite way to GAs. Naphrom et al. (2004) reported that high zeatin riboside (ZR) concentrations in all tissues are congruent with mango flowering under low temperatures. Upreti et al. (2013) observed that the cytokinins zeatin (Z), ZR, and dihydrozeatin riboside (DHZR), as well as total cytokinin contents, gradually increased in buds from 30 days before flowering until dormancy breaking in 'Totapuri' mango. Antara et al. (2019) said that Z contents increased during bud growth and were higher at panicle emergence for the cultivars Amparali and Dashehari. In a study on 'Alphonso' mango trees, Burondkar et al. (2016) identified that ZR was the prominent cytokinin in the buds of control trees and that total cytokinin content increased significantly in buds from 15 days before until dormancy breaking and decreased after 15 days from dormancy breaking. These authors also recorded an increase in mean ZR values by 241% in buds from 15 days before dormancy breaking, but leaf concentrations remained practically unchanged.

Auxins (AUs) also have effects on mango flowering. However, studies on this hormone are scarce in the literature, and some have poor methodological consistency. AU effects on flowering may be indirect, as according to Taiz et al. (2017), the hormone can indirectly stimulate root-produced CKs promoting new root growth points. Thus, by associating the fact that AU is transported basipetally from the apical bud, the interaction AU reduction and CK accumulation in resting buds may explain the cyclic nature of shoot initiation. The ratio between cytokinin and auxin levels in buds regulates bud initiation (Beveridge et al., 2003). Specifically regarding AUs, Capelli et al. (2021) evaluated 'José' and 'Cagshall' mango trees in France and observed that indole acetic acid (IAA) concentrations were high in inflorescences, fruit peduncles, and inflorescence or fruit axes, inhibiting vegetative growth of shoots in flowering and fruiting axes. These authors also identified that, although IAA concentrations during the cycle were low, they were higher in floral buds and fruit sets during initial growth and fruit maturation for both cultivars, thus remaining high during inflorescence and fruit development in branches. Conversely, Burondkar et al. (2016) identified an auxin (IAA) reduction from 15 days before until dormancy breaking. Such inconsistent results may stem from different climatic and management conditions and, more specifically, the varieties used. Another important factor refers to the method adopted, because when very small concentrations are used, different measures of error and accuracy can lead to different reference values. Bajpai et al. (2021) found AU content in juvenile shoots of the mango cultivar 'Amrapali' (3.01 $\mu g\ g^{-1}$ fresh weight) almost equal to that in flowers of alternating-production varieties. Therefore, maximum AU levels were responsible for floral induction intensity, as 'Amrapali' is a regular flowering cultivar, in which most shoots flower. By contrast, the varieties with lower AU content in vegetative shoots showed a flowering typical of alternating intensity. At flowering, there was low IAA oxidase activity, which may have increased AU amounts.

Another hormone that has also been reported to actively participate in mango flowering is abscisic acid (ABA). According to Capelli et al. (2021), ABA concentration remains higher in quiescent buds than in other buds, with however an increase or relatively high concentration in flowering and fruiting branches at the end of fruit development. Burondkar et al. (2016) found that mean ABA values increased by 32.5% in buds from 15 days before dormancy breaking. According to Upreti et al. (2013), high ABA levels provide the necessary internal condition for flower bud differentiation in mango. These authors identified a progressive increase in ABA concentrations in buds until dormancy breaking, recording an increase from 135.41 ng g^{-1} to 186.64 ng g^{-1}, therefore, 45.22% from 30 days before until bud dormancy breaking. The role of high ABA content in mango flower bud formation was reported by Chacko (1986), yet it is expected to induce bud dormancy, which consequently helps in floral bud formation, as mango flowering occurs in resting buds. According to the literature, ABA apparently has a positive role in mango flowering, but its degree cannot be estimated, especially due to the low concentrations found in the consulted papers. Therefore, one can infer that it is an important adjuvant in the process, as it inhibits vegetative growth, helping to increase bud reserves (Barbier et al., 2019).

The involvement of endogenous ethylene in mango flowering is not yet properly described in the literature. Still, ethylene-releasing chemicals such as ethephon have been used commercially to induce or assist in flowering uniformity. This response, however, is not consistent nor is there consistency in endogenous levels of ethylene to support its role in flowering. When evaluating different mango cultivars, Saidha et al. (1983) observed that ethylene levels gradually increase two months before flowering, followed by a marked reduction at flowering time; moreover, flowering shoots have 3 to 5 times more ethylene than vegetative shoots.

Protacio et al. (2009) studied mango flowering and ascertained important variables, including ACC and ethylene levels. These authors observed a reduction in ethylene levels close to flowering, while 1-carboxylic acid-1-aminocyclopropane (ACC) content in leaves remained stable or unchanged in control plants. Yet, plants treated with paclobutrazol (PBZ) for flowering management had increases in ACC levels, reaching a peak in the third month after application, coinciding with the beginning of flowering. This result indicates potential involvement of the ethylene biosynthetic pathway with floral initiation in mango trees, especially since ACC is widely recognized as an ethylene precursor.

In practice, the use of such technology has satisfactory results (personal experience). However, there is still no support or numerical indication of functionality in the scientific literature. When there is application of synthesis-inducing or ethylene-releasing products, mango trees express visual symptoms such as latex extrusion from terminal buds at inflorescence initiation and mature leaf epinasty near the apex (data not shown).

Changes in concentrations of some hormones in mango trees occur concomitantly with increases in carbohydrates, as a decrease in gibberellins favors synthesis of simple carbohydrates. It is because one of the main effects of gibberellins is to mobilize carbohydrates, stimulating their degradation into simple sugars (Prasad et al., 2014). Thus, an environment in which gibberellins are high does not promote starch accumulation, which is deleterious to mango flowering. Hormonal balance was also addressed by Bajpai et al. (2021) as an important factor in mango flowering, to the detriment of individual concentrations of each hormone. These authors infer that a lower level of gibberellins and higher levels of cytokinins, growth inhibitors, and ethylene have been indicated as the main favorable factors for inducing flowering in mango.

2.2.4 Genetic factors

Mo et al. (2021) isolated and identified two short vegetative phase (SVP) genes in 'SiJiMi' mango, MiSVP1 and MiSVP2. SVP is a transcription factor that integrates flowering signals and regulates flowering time. In this study, the authors found that both MiSVP genes were expressed during floral development and highly expressed in vegetative tissues, with low expression in flowers and buds. An evaluation in Arabidopsis revealed that MiSVP1 overexpression delayed flowering time and MiSVP2 overexpression sped up flowering time.

Fan et al. (2020) evaluated the role of FLOWERING LOCUS T (FT) in 'SiJiMi' mango and identified three MiFT genes belonging to the PEBP (phosphatidylethanolamine-binding protein) family. Their respective roles in flowering regulation in open reading frames of MiFT1 (mature leaves), MiFT2 (mature stems), and MiFT3 (flowers) were 540, 516, and 588 bp in length and encoded 180, 172, and 196 amino acids, respectively. Expression levels of the three MiFTs were significantly different in leaves during flower development, and MiFT1 expression markedly increased in leaves and was significantly higher than that of the other two MiFTs during flower bud development. This finding led the authors to believe that MiFT1 may act as a key regulator in flowering.

Patil et al. (2021) investigated genetic reasons for alternating production of 'Ratna' mango, using genes associated with flowering induction, repression, and regulation. FLOWERING LOCUS T (FT) genes that induce flowering and two TERMINAL FLOWER1 (TFL1) genes that repress flowering were identified and characterized. The authors found that GI-FKF1-CDF1-CO module can be used to regulate mango flowering and temperature-dependent flowering in mango can be associated with temperature-sensitive elements in the promoter region of one of the GIGANTEA genes, which are closely associated with floral induction.

Wang et al. (2022) also analyzed the gene expression of three FT-like genes (MiFT1, MiFT2 and MiFT3) and two TFL1-like genes (MiTFL1 and MiTFL1a) in 'Alphonso' mango trees. They found that MiFT2 expression was not detectable at any stage; therefore, it may be non-functional. However, MiFT1, MiFT3, and both TFLs were the main regulators of mango flowering.

3. Feasibility of mango production with natural flowering

The information available in scientific literature on economic viability, cultivar, productivity, fruit postharvest quality, and mostly associated cultural practices that can make production feasible will be addressed. Moreover, biodynamic, organic and agroecological production will be checked in the literature to provide a technical description of the cultivation modalities worldwide.

The search for sustainable agriculture and consumer markets interested in healthier and environmentally friendly products, such as no use of synthetic chemical inputs in food production, serve as a stimulus for organic food production to most farmers, regardless of their production scale (Padua et al., 2013). In this context, agroecological food production is directly related to sustainability and the environment, as it includes preservation of soil and water resources (Andrade et al., 2017). According to Dias et al. (2015), both consumption and development of organic and agroecological agricultures are in expansion. This understanding takes place at a global level, in a market that exhibits expansion rates above 20% across the planet. Therefore, attention has focused on the demand for such commodities, as well as on methods to ensure their suitable supply, quality, and certification (Muñoz et al., 2021).

This scenario applies not only to grain and cereal products, but also fruit production. In particular for mango, commercial fruit production with minimal cultural management, low-cost inputs, and farming practices dating back into antiquity may be possible, but many prerequisites need to be established and met.

As described in item 2 of the review, mango flowering is complex and affected by environmental factors (air temperature, photoperiod, and rainfall) and plant-related factors (cultivar, nutritional status, photoassimilates, enzyme activity, and plant hormones) interdependently. Effect of air temperature on mango flowering depends on the cultivar and management adopted. If considered only environmental conditions (Table 1), flowering occurs naturally in mango trees at temperatures between 11.9 and 39.1°C, regardless of management and cultivar.

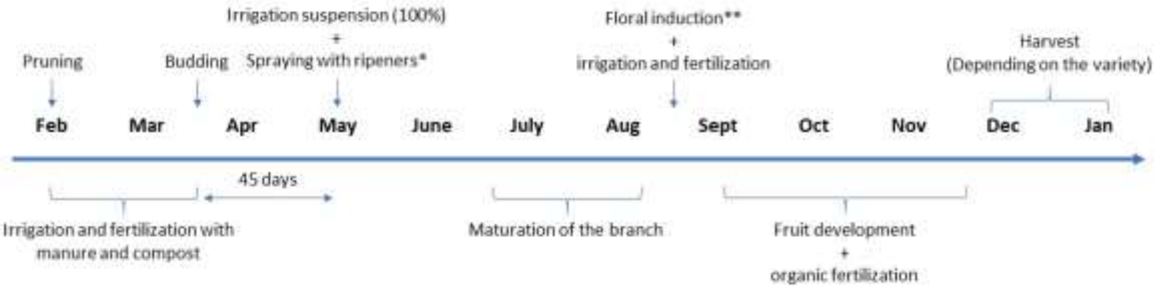
Regarding rainfall, absence or maximum of 60 mm from 4 to 5 months may favor flowering. It should be noted that rain not only acts in the ideal carbohydrate accumulation (Lopes et al., 2021) and hormonal balance (Cavalcante et al., 2020; Silva et al., 2021) for flowering, but also provides nitrogen, a nutrient known for affecting floral induction if above the maximum for each mango cultivar.

Environmental factors are clearly limited geographically and/or temporally so that they could act in mango flowering in regions that naturally it does not occur. Thus, regions with very high rainfall and absence of low temperatures, especially during floral induction (Moura et al., 2015; Caldana et al., 2020), will hardly provide natural flowering, given the requirement of these factors and lack of substitute chemical tools such as PBZ (Silva et al., 2021).

For Carr (2014), in the tropics, irrigation management with water stress promotes flowering after 6 to 12 weeks, while in subtropical and semiarid areas irrigation is crucial for important phenological stages for fruit production under high temperatures. According to Zuazo et al. (2021), in the tropics, water stress plays an important role in flowering and fruiting, as it favors floral induction.

When environmental conditions are not limiting, other factors may and should be managed to produce mangoes with a natural flowering. Under natural conditions, production alternation becomes a striking feature and is caused by the heavy fruit load of perennial fruit trees during productive year. This is, in part, because of the by low carbohydrate levels left after the productive year (Pongsomboon et al., 1997). One of the factors is soil because, according to Kumari et al. (2020), fruit plants are considered the most efficient biological systems. They effectively transform atmospheric carbon dioxide into long-lived soil carbon, despite its nutritional and export value. Greater carbon stocks help to sustain soil production and ecosystem services; therefore, better crop nutrition promotes carbon stock. The authors cited assessed the feasibility of integrated nutrient management to improve soil properties, nutrient availability, fruit production, and carbon stock in mango trees. They concluded that those practices such as application of manure corral, vermicompost, and organic cover with straw maintain fruit production and carbon stock in the soil, as well as promoting soil CO_2 sequestration and decreasing greenhouse gas emissions. These are all economically viable options since they mitigate climate change.

Given the importance of sustainable use of agricultural inputs and need to rationalize mango production systems, in 2020 the first organic mango production system was launched in Brazil (Embrapa, 2020). Recommendations are directed to the varieties 'Palmer' and 'Ubá' and to a specific region, Chapada Diamantina. However, they may serve as a model, after made the proper adjustments, for other producing regions. The floral induction recommended is described in Figure 1.



*Potassium sulfate and sulpomag (22% K_2O, 18% MgO, and 22% S) at 2% (20 g L^{-1}) concentration. Between two and three sprays may be carried out, starting 45 days after vegetative shooting (coriaceous mature leaves), and every 20 days between sprayings, alternating the sources.

**Biofertilizer sprays are recommended, such as fermented cow urine, at a concentration of 7% (70 ml L^{-1}) and divided into four weekly applications.

Figure 1. Diagram of management recommendations for flowering of Ubá and Palmer mango cultivars in Chapada Diamantina (Brazil) under an organic system recommended by Embrapa (2020) and adapted by the authors.

While the mango cultivar 'Ubá' is polyembryonic, 'Palmer' has a simpler flowering management compared to the others. For the conditions in Chapada Diamantina (Figure 1), the onset of flowering signs coincides with low ambient temperatures between June and August (minimum between 17 and 18ºC and maximum between 27 and 28 ºC), as well as lower rainfall from May to September (non-shown data). For Embrapa (2020) the 'Palmer' mango orchard yielded 15 t ha^{-1} in its fifth cultivation year, but no fruit quality parameters were assessed.

Prates et al. (2021) performed a review to compile information on updates and efforts to solve problems in conventional mango crops and pinpoint alternatives for organic management. They concluded that, in tropical regions, flowering rates should be improved by irrigation management (partial drought stress) and proper nutritional supply, with maintenance of pruning.

Despite the feasibility of commercially producing mango naturally ripened, a few bottlenecks still need to be overcome. One is economic viability since it becomes more expensive due to lower yields. Moreover, there is a lack of consistent and reliable data on specific management for each system, considering crop phenological phases. Lastly, market windows are narrowed down by climatic needs for flowering, limiting product supply time.

Naturally ripened mango should also consider the use of biological inputs although information is scarce in the literature. There are also few studies comparing biological and chemical fertilizers. The latter are widely used in mango cultivation and have had massive costs in recent years. One way to improve chemical fertilizers efficiency, plant nutrition, and hence production system sustainability is using biofertilizers. According to Vessey (2003) and Santana et al. (2017), this input contains live microorganisms that, when applied to plants or directly to the soil, colonize rhizosphere or inner part of plants, promoting plant growth by increasing nutrient supplies and/or availability. Biofertilizers have humic substances (Lagreid et al., 1999) formed by transformation of biomolecules during plant and animal residue decomposition. These compounds are the result from organic matter fractioning into humic acids, fulvic acids, and humines. Humic substances have been proven to improve soil physical and chemical traits, with direct effects on growth, development, nutrient absorption and, for many crops, yield and fruit quality.

Specifically in mango trees, application of biofertilizers via fertigation have promoted satisfying results, as they reduce synthetic fertilizers use, improve soil fertility, besides increasing production and physicochemical quality of fruits. According to Poonia et al. (2018), Kumari et al. (2020), Dalvi et al. (2021), and Prates et al. (2021), these inputs can be added to the production system of this crop. However, further studies are needed to provide accurate information and technical recommendations for mango cultivation using biofertilizers, without compromising productivity or fruit quality.

4. Mango flowering management

In this topic, we present information available in the literature regarding the main management practices adopted in traditional mango production in the following subtopics:

4.1 Pruning

Pruning is one of the most important cultural practices in mango orchards. It aims to shape plant canopy and maintain a balanced vegetative growth in the entire canopy area, preserving balance between plant roots and shoot. Thereby, vigor, flowering, and production are regulated, maintaining balance in fruiting, avoiding alternations between productive and poor seasons (Mouco and Albuquerque, 2004). Thus, off-season productions may be feasible (Ramírez and Davenport, 2010) since light penetration into canopy, fruit production, and photoassimilates use are optimized (Solanki et al., 2016).

In Table 7 there are the main results of the pruning effect on mango flowering.

Table 7. Effect of pruning on mango flowering.

Local	Climate	Cultivar	Main results	Reference
Petrolina, BR	Tropical semiarid	Tommy Atkins	Canopy closure of mechanically pruned trees occurs 90 days after pruning (DAP) and in manually pruned trees it is up to 122 DAP	Lopes et al. (2021)
Petrolina, BR	Tropical semiarid	Tommy Atkins	Fruit production is higher when productive branch density is also higher in plant canopy	Ferraz et al. (2020)
Australia	Subtropical	Honey Gold e B74	Pruning timing influences flowering. Control plants had 51 ± 2.22% of canopy flowered, while those pruned eight weeks later (Times 2) had 95 ± 1.45% of canopy flowered	Sarkhosh et al. (2018)
Australia	Not informed	Non-informed	The best response was obtained with moderate pruning, with severe pruning resulting in fewer inflorescences with fruits	Menzel and Lagadec (2017)
Viçosa, BR	Mesothermic	Ubá	Tip-pruning increased flowering from about 40% to 80% in plant branches	Oliveira et al. (2017)

Egypt	Desert	Alphonso	Pruning half the length of terminal shoots increased the number of panicles per plant from 153.7 (whole branch pruning) to 205	Elkhishen (2015)

DAP: days after pruning

Canopy light penetration is crucial for a uniform flowering in mango trees. A greater canopy exposure improves light use, increasing photosynthetic rates (Sharma and Singh, 2006). This is particularly so because mango growth and reproduction are often linked to axis morphology and its position within tree architecture, which varies with the cultivar used (Normand et al., 2009).

Menzel and Lagadec (2017) claimed that photosynthetic rate can be used as productivity index. Although, excessive pruning may reduce leaf area which, in turn, supports crop development. The authors also verified that pruning and tip-pruning increased the number of inflorescences with fruits in all canopy parts. According to them, moderate pruning had a better performance than severe pruning. The latter resulted in fewer inflorescences with fruits in the upper part and whole canopy. Moreover, they stated that pruning causes no increase in inflorescence relative distribution, with fruits in different canopy parts. Lastly, severe pruning may have increased light levels but at the expense of leaf area reductions, decreasing crop development support.

Davenport (2009) reported that mango leaves are demanding on sunlight for flowering under unfavorable inductive conditions. Branches exposed to lower light intensities tend to produce vegetative branches, while those exposed to full sun initiate reproductive branches. Besides, another important principle that governs pruning is related to apical dominance, which is described as the control exerted by the apex of shoots over the growth of lateral shoots. While the apical shoot remains intact, there is little or no growth of lateral or axillary shoots, and their removal breaks apical dominance and one or more lateral shoots may grow. This dominance is mainly regulated by auxins that are produced at the apex and transported by the basipetal pathway, inhibiting lateral shoots (Aloni, 2021).

Scarpare Filho et al. (2011) reported that drastic pruning can delay both flowering and fruiting. This is because, after drastic pruning, vegetative growth increases, delaying reproductive functions. In addition, drastic pruning makes branches more vigorous, with sap circulation becoming more intense in straight vertical branches. While these provide vegetative growth, horizontal branches favor reproductive buds, as they increase accumulation of reserves and favor formation of floral buds.

When aiming at mango flowering, more than one pruning step is performed during the phenological cycle. Pruning that starts the production cycle, also known as post-harvest pruning, must be associated with the opening of the middle of canopies (with height reductions if necessary), canopy lifting, branch diameter selection (above 8.0 mm), and tip-pruning of branches in induction. Ferraz et al. (2020) evaluated the cultivar 'Tommy Atkins' and illustrated the procedures performed in mango pruning. The illustration shows that production pruning can be done mechanically to achieve a trapezoidal shape (dotted line). For these authors, the lower part of the canopy can be pruned manually, as shown in Figure 2. The figure also shows a division of different evaluation heights, as indicative parameters of pruning success.

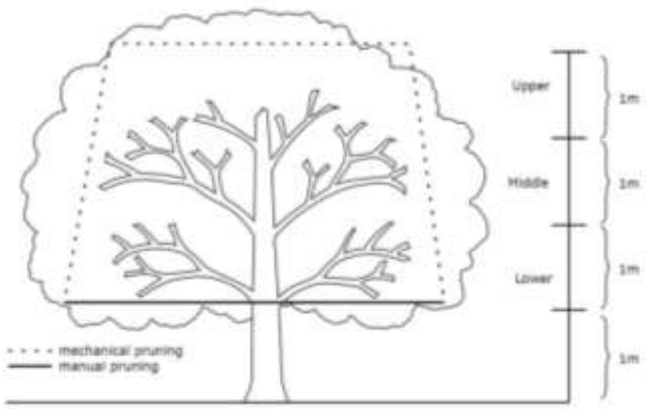


Figure 2. Mango pruning design and visual expression of different heights of canopy branches assessment (upper, middle, and lower). Source: Ferraz et al. (2020).

Furthermore, pruning (manual or mechanical) influences light interception by plants (Lopes et al., 2021). It is noteworthy that canopy closure in mechanically pruned plants occurs 90 days after pruning (DAP), whereas in manual pruning it is up to 122 DAP. Therefore, light interception is higher in mechanically pruned plants.

Ferraz et al. (2020) studied the mango cultivar 'Tommy Atkins' grown in the Brazilian semiarid region and concluded that, in trees mechanically pruned in a trapezoidal shape, the number of terminal branches, branch density, fruit density, and number of fruits per branch vary with the side (east and west) and position in the canopy. Terminal branches and fruit production concentrates to the west side of the plant and lower part of the canopy. The authors noted that in high-yield orchards pruned in a trapezoidal shape, the number of fruits per terminal branch is 1.15.

In the desert conditions of Egypt, Elkhishen (2015) evaluated four pruning treatments, removal of half-length terminal shoots, removal of whole terminal shoots, tipping, and control (no pruning) and concluded that removing half-length terminal shoots from was the most effective treatment to regulate flowering and productivity for the cultivar Alphonso.

Tip-pruning, known in Brazil as "*poda de desponte*" (in Portuguese), can also have positive effects on mango flowering. Oliveira et al. (2017) studied the effect of PBZ associated with the sprouting of 'Ubá' mango branches and reported that plants with branch sprouting had a greater number of panicles per branch and, consequently, increased number of fruits per branch, without deleterious effects on fruit quality. On the other hand, the need for tip-pruning or not depends on branch maturity and has to be evaluated by an experienced producer/consultant. Moreover, it is not a practice automatically included in the production of high-performance mango varieties.

Persello et al. (2019) evaluated two mango pruning factors: pruning intensity, defined at the tree scale as the amount of fresh biomass removed per unit of canopy volume; and pruning severity, defined at the axis scale as the distance between the pruning point and the distal end of the axis. The authors concluded that vegetative growth intensity increased with pruning severity (pruned axes) and axis diameter (pruned and unpruned axes) but was not affected by pruning intensity. They also observed that pruning intensity and severity influenced the dynamics of vegetative growth. Although these authors did not directly assess mango flowering, the increase in plant branches consists of an important measure. According to Ferraz et al. (2020), increases in plant branches may lead to a proportional increase in number of fruits per plant.

According to Sanjay et al. (2010), pruning timing and severity not only change mango physiological state but also alter biochemical properties, which can be observed through flowering, fruiting, and production patterns. These authors also verified that new branches from production pruning had more total and reducing sugars in relation to unpruned branches, which is positive due to the effects of these compounds on flowering (see item 2.2.2 of this review).

In Australia, Sarkhosh et al. (2018) evaluated the effect of six tip-pruning times between April and July (cooler and dry weather) at four weekly intervals, in two commercial mango cultivars (Honey Gold and Calypso - B74). These authors observed that control trees had 51 ± 2.22% of their canopy flowered, while those pruned eight weeks later (Times 2) had 95 ± 1.45% of their canopy flowered.

Singh et al. (2010) studied the effect of pruning intensity on flowering traits in 'Amparali', 'Malika', and Dashehari' mango trees in India and found numbers of panicles per branch between 3.85 in unpruned plants and 5.66 in trees under moderate pruning, in which 60 cm plant material was removed from the apex of the branch.

Quijada et al. (2009) obtained satisfactory results from the use of pruning in mango trees when compared to unpruned plants; they found an improvement in production when it was associated with application of potassium nitrate (KNO_3).

Ramirez et al. (2010) highlighted that branch age is a key factor for mango flowering and that each mango cultivar (even if mono-embryonic) has its individual features. They noted that synchronous generative shoot initiation in ‘Keitt’ trees occurred in about 75 and 100% of the branches after KNO_3 spraying 5 and 6 months after pruning date, respectively. However, the cultivar 'Tommy Atkins', which has more difficulty in inducing flowering than 'Keitt', had 18% of shoots flowering after 5-month application and 100% after KNO_3 application, 6 months after pruning. Moreover, they found that none of the untreated orchard trees flowered during this period. In short, these findings indicate that not only branch age (maturity) is necessary, but also pruning so that the age of branches is standardized and hence promoting a uniform flowering.

4.2 Irrigation management

Irrigation management in mango orchards affects flowering uniformity. Proper management must consider plant demands at each phenological stage to be successful, but especially the use of nitrate sources during shoot maturation, a phase that precedes floral induction. Moreover, many of the results found in the literature are inconsistent, as the studies were conducted using different technological levels, varieties, climates, and soils. These divergences do not allow the management to be applied in other mango producing regions of the world. Therefore, a suitable management must consider the specificities of each orchard and production system.

Older (Bally et al., 2000) and even recent (Halder and Hasan, 2020) literature have advised suspension of irrigation to stimulate water stress in mango trees, regardless of the mango cultivar and production system. However, the practice is extremely not recommended since other factors are involved in the flowering process, which can and should be considered. The main impact is growth stoppage that prevents plants to vegetate, in addition to decreasing gibberellin synthesis, a growth promoter. Branch maturation acceleration by water shortage is related to ethylene and abscisic acid synthesis. It, in turn, speeds up and standardizes branch maturation and hence flowering uniformization.

Deficit irrigation is a practice commonly used in mango cultivation. The technique consists of partially supplying crop water demand during stages in which the growth is little affected (Sampaio et al., 2010). This stress aims to increase water-use efficiency (WUE), because when water availability is a limiting factor, deficit irrigation can allow greater economic, environmental, and physiological returns. Previous studies have shown that in addition to saving water, water deficit can maintain or even increase fruit yields, as well as improve fruit quality.

The crop coefficient (Kc) values of mango trees are often low and depend on the climatic conditions of the growing region. In Egypt, Mattar (2007) reported that Kc values for flowering, fruiting, and fruit growth are 0.66, 0.85, and 0.88, respectively. Likewise, in Brazil, Coelho et al. (2002) pointed out that mango Kc should increase from 0.39 at flowering to 0.85 during fruit growth. By contrast, Mohammad et al. (2015) reported almost unchanged values between 0.71 and 0.77 for the entire production period. However, Sousa (n.d.) indicated that 0.39 would be a more suitable Kc value for the maturation of branches, and added that at flowering, as a whole, Kc values are above 0.60, ranging from 0.50 to 0.70 (Table 8).

Table 8. Crop coefficient (Kc) values for high-yield mango cultivation in Brazilian semi-arid.

Stage	Kc	Beginning (DAP)	End (DAP)	Duration (days)
Pruning - Vegetative growth 1	0.6	1	40	40
Vegetative growth 2	0.7	41	120	80
Vegetative growth 3	0.6	121	130	10
Water stress 1	0.5	131	140	10
Water stress 2	0.4	141	150	10
Water stress 3 – Branch maturation	0.3	151	180	30
Flowering 1	0.5	181	190	10
Flowering 2	0.6	191	200	10
Flowering / Fruiting	0.7	201	230	30
2nd Physiological fruit drop	0.9	231	250	20
Fruit growth 1	0.7	251	280	30
Fruit growth 2	0.6	281	290	10
Fruit ripening / harvest	0.5	291	330	40

DAP – days after pruning. Source: Adapted from Sousa (2015)

In Petrolina, Silva (2000) recommended Kc values of 0.44 for 'Tommy Atkins' mango at flowering, 0.65 at fruit dropping, 0.83 at fruit formation, and 0.84 at fruit ripening. Nevertheless, Sousa (n.d.) considered that 0.44 is a substantially low value and that one should specify which flowering phase it refers to. The author inferred that it might refer to the initial flowering phase, that is, between the end of branch maturation to the emergence of flower buds.

Teixeira et al. (2008) reported Kc values from 0.65 to 1.05, with higher values when topsoil had been often wetted by rain or irrigation. On the other hand, it is worth noting that, according to Sousa (n.d.), in general, few large fruit trees, such as mango, have Kc values above 0.90 at a stage of greater water demand (Allen et al., 1998), and that methodological errors may have occurred, such as the "bouquet effect", which causes an overestimation of Kc.

Zuazo et al. (2019) carried out a lysimeter experiment with the 'Osteen' mango in Granada, Spain, aiming to evaluate plant water-use efficiency through Kc values. They observed that Kc values presented three main stages during the mango phenological cycle, being flowering (Kc = 0.43), fruit setting (Kc = 0.67), and fruit growth (Kc = 0.63). At the same time, another study performed by the same group of researchers (Pleguezuelo et al., 2018) recorded different results for Kc, obtaining values of 0.51, 0.72, and 0.60 for flowering, fruit setting, and fruit growth, respectively.

In a comprehensive review of water relations and irrigation requirements for mango, Carr (2014) concluded that Kc value varies between 0.65 and 1.05, with the frequency and extent of soil surface wetting (linked to irrigation method), as well as vegetative canopy density. However, this author may have overestimated wet area and Kc adequacy, obtaining higher Kc values as discussed by Sousa (n.d.), which is dangerous for the productive system of mango trees.

Levin et al. (2015 a, b) reported that more severe water stress during the post-harvest period results in earlier flowering. The authors observed that trees under deficit irrigation (mainly T-1) flowered earlier than those receiving higher irrigation depths (T-3 or T-4). However, treatments did not affect flowering intensity.

Santos et al. (2015) evaluated the effect of different ETc values on 'Tommy Atkins' mango in Brazil, namely: a) irrigation with 100% ETc; b) irrigation with 100% ETc alternating emitter side every 15 days; c) irrigation with 80% ETc alternating emitter side every 15 days; d) irrigation with 60% ETc alternating emitter side every 15 days. The Kc used to calculate evapotranspiration during assessment phases ranged from 0.45 to 0.87, as done by Cotrim et al. (2011) and recommended by Coelho et al. (2002).

Side switching of irrigation emitters has been studied by many authors and apparently may be a relevant strategy (Sousa, n.d.). In a study on mango of the cultivar ‘Chok Anan’, Spreer et al. (2009) evaluated plant response to different levels of available water using a Kc of 0.80 for the control. They observed that a reduction of 50% of this value decreased productivity by only 3%, with better results for the partitioning of water extraction (alternating sides of irrigation in drip irrigation systems, with two lines of drippers per row of plants) in dry years.

Fonseca et al. (2018) studied organic cultivation of 'Ubá' mango in Lençóis, Brazil, and reported that flowering percentages ranged from 17.59% for application of 100% irrigation depth and 45.25% for application of 50%, during 120 days. When comparing both treatments, they observed a 156% increase in flowering rate with water deficit. However, it is important to highlight that the study region has a mild climate during the flowering induction phase.

In research carried out with ‘Kent’ mango trees in the Brazilian semi-arid region, Simões et al. (2021) concluded that a reduction in irrigation depth by up to 60% of ETc increased water-use efficiency, but the highest net revenue was obtained with a depth of 80% of ETc. Also, for the cultivar ‘Kent’ in the Brazilian semi-arid, Silva (2019) assessed the effect of five irrigation depths (24, 36, 48, 60, and 100% of the ETc) and identified that an irrigation depth of 54% of the ETc promoted a higher number de plant inflorescences (102). These authors used the Kc values for ETc calculation ranged between 0.3 and 0.8 with phenological phase studied, whereas the Kc used in the farm studied was 1.0, thus a reduction of 0.54 is suggested.

Reducing irrigation level to 0% or 25% of the ETc at flowering and 100% of the ETc at fruiting stage may stimulate floral induction for mangoes of the cultivar 'Tommy Atkins' grown in the Brazilian semi-arid regions (Faria et al., 2016). In these studies, the Kc values used to calculate ETc ranged from 0.3 to 0.8, depending on phenological phase.

As in Table 8, Sousa (2015) suggested Kc values for high-yield mango cultivation grown in the Brazilian semi-arid region.

In a study with mangoes of the cultivar 'Kent', Silva (2019) found Kc values quite discrepant from those in the literature in different phenological stages, including small variations in Kc values between the phenological phases (Table 9).

Table 9. Reference evapotranspiration (ETo), crop evapotranspiration (ETc), and crop coefficient (Kc) for irrigated 'Kent' mango trees grown in the submedium São Francisco Valley.

Phenology	ETo (mm)	ETc (mm)	Kc
Vegetative growth	4.98	4.27	0.88
Flowering	3.94	3.33	0.84
Fruit drop	4.52	3.63	0.81
Fruit formation + ripening	6.12	4.45	0.73
Average	5.10	4.08	0.82

Source: Silva (2019)

In fact, proper mango irrigation management in both tropical and subtropical conditions is essential for uniform orchard flowering. However, stress management must consider soil conditions, cultivar used, and air temperature (day and night), so it must not be uniform for all orchards.

4.3 Fertilizer management

Fertilizer management aimed at a suitable nutritional status of mango trees also influences their flowering, mainly in relation to nutrients with specific effects on this phenological event. Among the nutrients that should be paid more attention in relation to flowering, nitrogen, potassium, calcium and boron stand out.

Nitrogen affects flowering in two different ways, either through excess or deficiency. It is already known, and was discussed in topic 2.2.1, that excess nitrogen in the plant negatively interferes with floral initiation in mango plants (Litz, 2009; Ramírez and Davenport, 2010). However, panicle growth, logically after floral bud setting, is influenced by N and should be considered in fertilization management.

There are different recommendations in the literature for nitrogen fertilizer distribution along the phenological cycle of mangoes. Silva and Faria (2004) recommend that N be managed aiming to reach 100% of the proposed fertilization recommendation, 50% after harvest, 30% after fruit setting, and 20% at 50 days after fruit setting. Conversely, Winston (2007), under conditions and varieties studied in Australia, recommended the following installment: 60-70% during vegetative growth (after pruning), 20-30% at flowering (flower already set), and 5-10% on early fruit development if needed.

Both recommendations above are not antagonistic and are interesting proposals. However, none of the cited authors considered the genotype factor (mango cultivar). Therefore, producers should be careful when splitting the fertilizers, especially for longer cycle cultivars. This is because the distribution of nitrogen fertilizers must consider each cycle duration, avoiding not concentrating applications and high nutrient losses by volatilization and deep percolation.

For 'Zebda' mangoes in Egypt, El-Motaium et al. (2019) concluded that nitrogen fertilization significantly increases inflorescence length. In 'Kent' mango trees in Brazilian semi-arid region, Lobo et al. (2019) identified that, before flowering, nitrogen content in the first season evaluated was 17.78 g kg^{-1}, and during the full flowering the average content was 14.84 g kg^{-1}; therefore, there was a decrease of 16.53% in a short period of time. These results indicate that nitrogen fertilization management should consider this consumption, but always having as a reference the foliar N content at the beginning of floral induction.

Hamilton et al. (2017) evaluated the effect of nitrogen fertilizer application time on fruit yield and leaf N allocation for 'Kensington Pride' mangoes as a function of varying N contents in leaf dry matter. They concluded that the rate of N from fertilizers was significantly higher in fruits from trees with low foliar N contents and when N was applied before flowering. The results indicate that leaf N allocation and N contents in mango trees differ depending on leaf N contents and fertilization time.

Nitrogen is an important element for mango tree vigor, as it stimulates vegetative and floral growths (Lopes et al., 2021). Yeshitela et al. (2005) reported that N in combination with K, such as KNO_3 and urea, increases percentage of terminal flowering shoots, but when in excess it stimulates vegetative growth at the expense of flowering. As for foliar fertilization, nitrate applications are known to have positive effects on mango bud breakage (Silva and Faria, 2004; Morales-Martinez et al., 2020) and hence flowering. However, little is known whether foliar applications of nitrate can supply N in plants, but in a way aimed at increasing foliar nitrate (NO_4).

A study by Patil et al. (2013) in India revealed that foliar application of KNO_3 and NH_4NO_3 are more effective in inducing post-harvest, profuse vegetative growth, and flowering. Likewise, KNO_3 (3%) resulted in significantly greater flowering and earlier induction of flowering with increased yield. To induce dormancy breaking of mango buds, Silva and Faria (2004) recommended foliar applications of potassium nitrate (2.0 to 4.0%), ammonium nitrate (1.0 to 1.5%), or of calcium (1.5 to 2.0%). These authors reported that number of applications would vary with plant physiological stage concerning other factors required for flowering already discussed. Oliveira et al. (2019) stated that three to five applications may be required; however, there are reports of up to eleven applications in cases of plants under extreme stress. Still, some studies have warned that applications should be suspended when more than 60% of the branches have emitted or mixed panicles.

Effects of nitrate foliar application on bud breakage and hence flowering induction come from nitrate action and not from any other accompanying nutrient. After application, nitrate reductase enzyme activity increases (Silva et al., 2021) and stimulates methionine synthesis, which, through the Young cycle, triggers ethylene synthesis, stimulating floral differentiation in physiologically mature of mango branches (Taiz et al., 2017).

Table 10 contains some results of the scientific literature about the fertilizing management on mango flowering.

Table 10. Effect of fertilizer management on mango flowering.

Site	Climate	Cultivar	Main results	Reference
Petrolina, BR	Tropical semiarid	Tommy Atkins	Nitrogen is important for inflorescence growth.	Lopes et al. (2021)
Phitsanulok, Thailand	Equatorial	Mahachanok	Four foliar applications containing calcium (calcium chelate – 13%), zinc (zinc chelate – 13%), and boron (boron chelate – 10%) at 2.5 ml L^{-1}.	Maklad et al. (2020)
Egypt	Desert	Zebda	Application of 0.3% humic acid with 600 mg L^{-1} boric acid twice before flowering, and a third spray 30 days after the first one, i.e., during the flowering period.	El-Hoseiny et al. (2020)
Petrolina, BR	Tropical semiarid	Tommy Atkins	Calcium in the form of $CaCl_2.2H_2O$: the highest flowering rates were reached via fertigation (29.33%) and foliar + fertigation (24.64%). Calcium complexed with organic or soluble acids, with amino acids applied via foliar route: higher flowering percentages (22.52% and	Tenreiro (2020)

			23.10%, respectively) in relation to Ca in the form of $CaCl_2.2H_2O$ (13.58%).	
Petrolina, BR	Tropical semiarid	Kent	Decrease of 16.53% in foliar N from induction to full flowering.	Lobo et al. (2019)
Casa Nova, BR	Tropical semiarid	Palmer	Potassium distribution in the cycle: 45% between pruning and induction, 20% after fruit set and 15% at 50 days after fruit set.	Carneiro et al. (2017)
Casa Nova, BR	Tropical semiarid	Palmer	There is an effect of B fertilization management on mango cultivation, with recommendation of five sprays with H_3BO_3 [first two 0.3% and the other 0.2%] in soil with 0.40 mg dm^{-3} of B.	Oldoni et al. (2018)
Australia	Subtropical	General	Nitrogen distribution in mango cycle: 60-70% at vegetative phase (after pruning), 20-30% at flowering (flower already set), and 5-10% at the beginning of fruit development if required. Potassium distribution in mango cycle: 20% at vegetative phase (after pruning), 20% at flowering (flower already set), and 60% in the early fruit development. Distribution of Ca recommended dose along mango cycle: 50% immediately after pruning, but divided into six weekly applications; 20% at panicle emission, but divided into three weekly applications; and 30% at fruit growth, but divided into five weekly applications. Boron distribution in mango cycle: 20% at vegetative phase (after pruning), 20% at dormancy stage, 40% between flower setting and early fruit development, and 20% at early fruit development.	Winston (2007)
Petrolina, BR	Tropical semiarid	General	Nitrogen distribution in mango cycle: 50% after harvest, 30% after fruit setting, and 20% 50 days after fruit setting. Potassium distribution in mango cycle: 25% after harvest, 20% before floral induction, 15% at flowering, 15% after fruit setting, and 15% 50 days after fruit setting. Aiming to induce flowering: sprays with potassium nitrate (2.0 to 4.0%), ammonium nitrate (1.0 to 1.5%), or calcium nitrate (1.5 to 2.0%).	Silva and Faria (2004)

Although K is used for cell division and expansion during all growth stages, particularly in fruit development (Cavalcante et al., 2016; Carneiro et al., 2017), this nutrient aids in translocation of sugars in plants (Cavalcante et al., 2018) and, therefore, influences mango flowering. Thus, K fertilization distribution within mango cycle must be adjusted according to its respective phenological events and including flowering.

Silva and Faria (2004) recommended managing K fertilization in order to apply 100% of the proposed dose: 25% after harvest, 20% before floral induction, 15% at flowering, 15% after fruit setting, and 15% 50 days after fruit setting. Conversely, Winston (2007) recommended for conditions and varieties studied in Australia the following distribution: 20% at vegetative phase (after pruning), 20% between flower setting and the beginning of fruit development, and 60% in the initial development of fruits. By contrast, Carneiro et al. (2017) adopted a recommendation of 45% between pruning and induction, 20% after fruit setting, and 15% 50 days after fruit setting and observed significant effects on 'Palmer' mango productivity under semiarid conditions.

Regarding changes in foliar K levels, Lobo et al. (2019) evaluated two 'Kent' mango seasons and observed a significant reduction in levels in two consecutive seasons between floral induction and full flowering, with decreases of 43.90% and 48.51%, respectively. In this study, K fertilization was carried out until branch maturation, which precedes induction, and it was resumed only during fruit growth.

Calcium is another key nutrient for mango flowering, as it takes part in cell wall structure. It is essential in the formation of new growth points (e.g., roots, rootlets, leaves, flowers, and pollen tubes), allowing cells to expand (Freitas et al., 2016). In this sense, calcined fertilizers must also be adjusted to periods of greater demand throughout mango cycle. As for Ca supply, soil pH has a very particular effect, as there is a need to increase soil pH; therefore, the use of limestone at the beginning of the productive cycle (pruning) is recommended but does not exclude its supplementation in other key phases such as flowering and fruit growth. The latter directed towards the post-harvest quality of fruits. In recent years, various calcined fertilizers have been made available to fruit growers, and some studies have shown that liquid or fine-mesh powders are absorbed more quickly and thus recommended for applications at flowering and early fruit development.

One of the above studies was carried out in the Brazilian semi-arid by Tenreiro (2020). They aimed to evaluate different Ca sources and application forms and the respective effects on flowering, productivity, pulp and peel nutritional contents and fruit quality for the mango cultivar 'Tommy Atkins'. The authors observed that in general flowering rates varied between 13.58% and 29.33. For the Ca source $CaCl_2.2H_2O$, the highest flowering rates were observed for applications via fertigation (29.33%) and foliar + fertigation (24.64%). When applied via foliar, the use of nobler sources of calcium, such as those complexed with organic acids or soluble with amino acids, presented higher flowering percentages (22.52% and 23.10%, respectively) compared to $CaCl_2.2H_2O$ (13.58%). On the other hand, $CaCl_2.2H_2O$ showed higher flowering rates than Ca complexed with organic acids and water-soluble Ca + L-a-amino acids when applied by fertigation.

Tenreiro (2020) distributed calcined fertilizers throughout the phenological cycle of 'Tommy Atkins' mango according to recommendations by Winston (2007), but with adjustments. They provided 50% of the recommended dose after pruning (subdivided into six weekly applications), 20% in panicle emission (subdivided into three weekly applications), and 30% in the fruit growth phase (subdivided into five weekly applications).

Most studies with potassium and calcium for mango orchards have aimed to evaluate fruit growth and development, specifically on growth and flavor (potassium) and firmness and postharvest time (calcium). However, only few studies have focused on flowering, especially with economically important varieties consumed in the United States and Europe. On the other hand, one of the most studied nutrients for mango flowering is boron, especially because it has great importance in fertilization, seed and fruit production, since it is required for pollen grain germination and pollen tube growth (Saran and Kumar, 2011).

An ideal management of boron fertilization is crucial to reach high yields. To do so, well-defined fertilizer strategies are required, including micronutrients such as boron, which is difficult due to the narrow range between its essential and toxic levels. Winston (2007) reported that under boron deficiency, mango trees have panicles with flowers bent at straight angles. These findings corroborate those of Silva (2008), who added that deficiency symptoms are more visible during flowering.

Barbosa et al. (2016) highlighted that most macro and micronutrient tables were made for non-irrigated conditions. Therefore, studies on B availability under irrigated conditions are still needed, especially in semi-arid regions where soil and climate conditions are peculiar. These authors also recommended that borate fertilization must be carried out before flowering by applying two fertigation treatments with 50 g of H_3BO_3 plant^{-1} plus five sprays with H_3BO_3 [first two (0.3%) and others (0.2%)].

Oldoni et al. (2018) evaluated the effects of boron fertilization on production and quality of 'Palmer' mango fruit and recommended five sprays with H_3BO_3 [first two (0.3%) and the remaining (0.2%)] into the soil with 0.40 mg B dm^{-3}.

El-Hoseiny et al. (2020) associated humic acids with boron to minimize alternate bearing in ‘Zebda’ mango and observed morphological, physiological, biochemical, and genetic effects. Such effects influence plant growth, yield, and fruit quality. They then recommended two sprays of 0.3% humic acid with 600 mg L^{-1} of boric acid before flowering, and a third 30 days after the first, i.e., still within the flowering period.

El-Motaium et al. (2019) evaluated the mango cultivar 'Zebda' in Egypt and found an interaction between nitrogen and boron fertilizations, especially when boron was used in the form of boric acid at a concentration of 250 mg L^{-1}. These authors also verified that the N x B association also reduced by 66% in alternate bearing alternate bearing under the regional growing conditions.

Maklad et al. (2020) evaluated the efficiency of foliar application of calcium, zinc, and boron, individually or in combination, at different times and concentrations on flowering, yield, and fruit quality and observed effects on panicle length, male flowers, hermaphrodite flowers and number of flowers per panicle, with effects on fruit production. These authors recommended four foliar applications containing calcium (calcium chelate – 13%), zinc (zinc chelate – 13%), and boron (boron chelate – 10%) at 2.5 ml L^{-1}.

Calcium and boron addition [40% calcium ($Ca (NO_3)2.4H_2O$) and 0.3% boron (H_3BO_3)] promoted an increase in pollen grain germination from about 25 to 60% (Muengkaew et al., 2017). This indicates the importance of these nutrients for the flowering of the ‘Mahachanok’ mango trees. At the same time, these authors also reported that foliar application of a Ca-B solution at a concentration of 3.0 mL L^{-1} also generated positive effects on fruit production and, consequently, productivity

Winston (2007) for the conditions and varieties studied in Australia recommended the following distribution of borate fertilizers: 20% during the vegetative phase (after pruning), 20% during dormancy, 40% between flower setting and the beginning of fruit development, and 20% in the early fruit development.

4.4 Use of growth regulators

Although mango flowering is regulated by a set of factors, as presented and discussed in the previous topics of this review, including hormonal balance, the use of growth regulators in mango production to have a positive impact on flowering is still restricted and does not constitute a consensus among the producers. The scientific literature available has highlighted the use of gibberellin synthesis inhibitors (paclobutrazol, uniconazole, metconazole, fenpropimorph, prohexadione-Ca, ethyl-trinexapac, and chlormequat chloride) and ethylene synthesis inducer (ethephon). Gibberellin inhibitors have been used commercially in several producing countries, especially paclobutrazol (PBZ). This product is specifically used on mango trees, without compromising the orchards' certification process. In fact, the results of using PBZ in mango farming depend on a number of factors, which include climate, soil type, mango cultivar, and dose applied in the previous cycle.

According to Oliveira et al. (2020), the application of 1 g a.i. of PBZ per linear meter of canopy in ‘Palmer’ mango results, at the cellular level, in reductions of starch reserves and accumulation of calcium oxalate crystals, phenolic compounds, and lipophilic substances in the mesophyll; floral differentiation requires 13 days (starting 103 days after PBZ application), with the formation of inflorescence and flower axes. In Mexico, Morales-Martinez et al. (2020) evaluated several PBZ treatments followed by nitrate applications in mango trees of the cultivar 'Tommy Atkins'. They recorded that the number of panicles per plant ranged from 136.0 ± 58.38 (control) to 288.5 ± 75.17 for PBZ at 1.0 g ai per linear meter of canopy diameter when associated with application of 6% nitrate. Lobo et al. (2019) tested biostimulants for 'Kent' mango in Brazil during two consecutive years and adopted a PBZ dose of 9 mL of commercial product (Cultar® with 25% PBZ) per meter of canopy diameter. It was higher than the maximum recommended by the manufacturer (6 mL m^{-1}), as the genotype has an intense vegetative vigor. The authors registered panicle lengths from 26 to 33.5 cm, with a number of fruits per panicle ranging between 1.2 and 2.0. Likewise, Souza et al. (2018) concluded that PBZ application in 'Palmer' mango via irrigation was more efficient at 1.3 g ai per linear meter of canopy. They observed that despite the greater productivity and number of fruits per plant, panicle lengths were reduced from 40 cm to 20 cm between the doses of 0.7 and 1.3 g ai per linear meter of canopy, respectively. Therefore, in spite of panicle compaction, there was no reduction in productivity. Yet for the mango cultivar 'Ubá', Oliveira et al. (2017) concluded that PBZ application up to a dose of 1.62 g ai per linear meter of canopy, combined with tip-pruning, increases flowering and has no effect on fruit quality. Husen et al. (2021) compared different PBZ and ethephon treatments for the mango cultivar ‘Arumanis’ in Egypt. They noted that PBZ potentiated flowering (flowering time, number of panicles, panicle length, panicle width, and immature panicles), while ethephon sped up flowering (number of panicles) compared to the control, especially at 400 mL L^{-1} and 600 mL L^{-1}. In India, Kishore et al. (2019) assessed the mango cultivar 'Arka Neelachal Kesari' and reported that PBZ advanced flower budburst and increased flowering intensity, percentage of bisexual flowers, fruit production, and productive efficiency at a dose of 0.25 g ai per linear meter of canopy. In mango cultivation, PBZ or any other gibberellin inhibitor may be associated with ethephon, depending on the mango cultivar vigor. More vigorous varieties tend to require the use of ethephon, depending on the climatic conditions (especially air temperature) during flowering induction. Certain temperatures, which are not very stimulating to flowering, may require the use of ethephon associated with PBZ, especially for more vigorous varieties such as ‘Kent’ and ‘Tommy Atkins’. In Malaysia, Afiqah et al. (2012) studied the effects of the following treatments on mango flowering: T1: control (normal practices); T2: KNO_3 sprayed at concentrations of 1, 2, and 5%; T3: PBZ applied to the soil followed by spraying of 2% KNO_3 and spraying of 2% ethephon; and T4: ethephon sprayed at 1, 2, and 5%. The authors concluded that PBZ application to the soil followed by foliar application of 2% ethephon was effective in increasing flowering of young mango trees of the ‘Chok Anan’ (MA 224). However, PBZ rates should be revised since the authors, unfortunately, did not inform the dose of PBZ adopted. Silva et al. (2021) found that 'Keitt' mango trees in the first production cycle in Brazil treated with 1.0 g ai PBZ per linear meter of canopy showed a minimum flowering percentage of 70%, reaching 100% when PBZ was associated with fulvic acid.

Uniconazole (UCZ) has also been used as gibberellin inhibitor in mango crops. In this sense, Lima et al. (2016) evaluated the effect of different doses of UCZ on several traits of 'Palmer' mango trees in Brazil. They found that all treatments using UCZ reduced branch elongation when compared to the control (81.6% reduction on average). However, only split application of 4.0 g ai UCZ/plant (1.0 + 1.0 + 2.0) every 30 days was efficient in promoting flowering in the off-season, allowing an average increase of 167% in number of fruits per plant. Likewise, Silva et al. (2014) evaluated UCZ application to irrigated 'Palmer' mango trees under semi-arid conditions in Brazil. The authors observed that foliar applications at 500, 1000, and 1500 mg L^{-1} of UCZ were not effective in controlling vegetative growth and promoting flowering. However, application of 6000 mg L^{-1} of UCZ to the soil increased the number of panicles per plant to 171, which is much higher than the control (32.25 panicles/plant).

Another gibberellin inhibitor with potential for use in mango production is metconazole (MTZ). Cavalcante et al. (2020) compared its use in 'Palmer' mango cultivation in the Brazilian semiarid with PBZ. These authors observed that MTZ at 1.3 g ai per linear meter of canopy has an inhibitory effect on gibberellin biosynthesis in mangoes, but affects AG1+AG3, and AG4 diversely. Although MTZ can potentially be used in mango flowering management, studies are still required to determine a specific practice.

Mouco et al. (2011) compared the foliar application of the growth regulators prohexadione-Ca, ethyl-trinexapac, and chlormequat chloride with the use of PBZ via soil on vegetative sprouting and flowering of 'Kent' mango trees in the Brazilian semiarid region. These authors found that PBZ at doses of 4.0 g ai per plant combined with prohexadione-Ca (1.0 g ai per plant) was more efficient in controlling the vegetative growth of 'Kent' mango branches, but not with regard to flowering, in which no significant differences were observed between treatments. The same regulators (prohexadione-Ca, ethyl-trinexapac and chlormequat chloride) were tested before by Mouco et al. (2010) as growth inhibitors in 'Tommy Atkins' seedlings. They concluded that all products applied via foliar are efficient in regulating vegetative growth in seedlings at 1.0 g ai per plant, in one or two applications of 0.5 g ai per plant, interspersed for 30 days. However, these authors did not assessed flowering, which does not allow making inferences directed in this regard.

Fenpropimorph (FPM) was studied as a gibberellin synthesis inhibitor in 'Tommy Atkins' mangoes by Carreiro et al. (2022a). They observed significant effects on gas exchange; therefore, it promotes a higher CO2 assimilation rate. Conversely, PBZ is more effective in chlorophyll a and total chlorophyll accumulations, while FPM did not affect these photosynthetic pigments. In another study, Carreiro et al. (2022b) evaluated FPM and concluded that, at a dose of 1.3 g ai per linear meter of canopy, this molecule is efficient in inhibiting GA3 biosynthesis and promotes accumulations of organic reserves in a similar way to PBZ but does not influence the vegetative growth and flowering of 'Tommy Atkins' mango in the tropical semiarid. Although FPM could potentially be used to inhibit gibberellin biosynthesis in mango, further studies are needed to determine specific management practices.

By contrast, gibberellin application can also be used to inhibit mango flowering at unwanted times. In this context, Oosthuyse (2015) recommended applying 100 ppm GA3 (ProGibb®) for the mango varieties 'Keitt', 'Kent', 'Tommy Atkins', 'Zill', 'Heidi', and 'Sensation'.

The main effects of plant growth regulators on mango flowering are in Table 11.

Table 11. Effect of growth regulators on mango flowering.

Site	Climate	Cultivar	Main results	Reference
Petrolina, BR	Tropical semiarid	Tommy Atkins	Application of fenpropimorph at 1.3 g ai per linear meter of canopy is efficient in inhibiting biosynthesis of gibberellic acid (GA3) and promotes accumulations of organic reserves in a similar way to paclobutrazol, but does not influence mango vegetative growth and flowering	Carreiro et al. (2022b)
Petrolina, BR	Tropical semiarid	Tommy Atkins	5.72 g PBZ per adult plant promoted a uniform flowering and yields from 15 to 26 t ha^{-1}	Lopes et al. (2021)
Cabrobó, BR	Tropical semiarid	Keitt	In the first production cycle, 1.0 g PBZ per linear meter of canopy promoted a minimum flowering of 70%, with a maximum of 100% when its was associated with fulvic acid	Silva et al. (2021)
Oaxaca, MX	Warm sub-humid	Tommy Atkins	Number of panicles per plant ranged from 136.0 ± 58.38 (control) to 288.5 ± 75.17 for PBZ treatment at 1.0 g ai per meter of canopy	Morales-Martinez et al. (2020)

			diameter associated with application of 6% nitrate	
Petrolina, BR	Tropical semiarid	Palmer	Metconazole (1.3 mL per linear meter of canopy) has an inhibitory effect on gibberellin biosynthesis, but affects AG1+AG3, and AG4 concentrations diversely	Cavalcante et al. (2020)
Janaúba, BR	Tropical semiarid	Palmer	For 1 g ai PBZ per linear meter of canopy, floral differentiation requires 13 days (starting 103 days after PBZ application), with the formation of inflorescence and flower axes	Oliveira et al. (2020)
Petrolina, BR	Tropical semiarid	Kent	The PBZ dose of 9 mL commercial product (Cultar® with 25% PBZ) per meter of canopy diameter promoted panicle lengths ranging from 26 to 33.5 cm, with number of fruits per panicle ranging between 1.2 and 2.0	Lobo et al. (2019)
Petrolina, BR	Tropical semiarid	Palmer	Panicle lengths reduced from 40 to 20 cm as PBZ dose increased from 0.7 to 1.3 g ai per linear meter of canopy, but with no reduction in productivity. The dose recommended by authors was 1.3 g ai per linear meter of canopy	Souza et al. (2018)
Nova Porteirinha, BR	Tropical semiarid	Palmer	A split application of 1.0 + 1.0 + 2.0 g ai UCZ per plant every 30 days via foliar route was efficient in promoting flowering in off-season, with an average increase of 167% in number of fruits per plant	Lima et al. (2016)
Petrolina, BR	Tropical semiarid	Palmer	Application of 6000 mg L^{-1} UCZ to the soil promoted an increase in number of panicles per plant from 32.25 to 171	Silva et al. (2014)

Maloba et al. (2017) compared the use of ethephon individually in the mango varieties ‘Apple’ and ‘Ngowe’ with ethephon plus potassium nitrate. They observed that spraying with 4% KNO_3 was beneficial for flowering and fruiting parameters and that ethephon can be sprayed at 600 ppm, since a dose of 1000 ppm had positive effect on flowering but increased fruit drop.

Commercial 'Kent' mango crops in Brazil often adopt foliar applications of Ethrel® varying doses from 0.1 to 25 ppm, with the number of applications depending on climate, soil, and plant nutritional/hormonal stages, using higher doses when conditions are more unfavorable.

4.5 Use of biostimulants

Mouco and Lima Filho (2004), aiming to elongate panicles and improve fruit setting for ‘Tommy Atkins’ mango grown in semiarid, used a biostimulant composed of 20% amino acids, 11% N, and 15% K_2O applied during flowering and fruiting. They concluded that these products were efficient in panicle expansion and fruit retention, with the best dose increasing the number of fruits plant-1 by 45.32%. In a study with the cultivar Haden in Petrolina, Pernambuco, Brazil, Mouco and Lima Filho (2004) compared the effects of isolated and associated applications of cobalt via soil and foliar with amino acids applied via foliar (0.1%) on panicle length and fruit setting. These authors found that the use of amino acid increased average panicle length by 6 cm, while cobalt applied via soil provided better fruit setting by reducing ethylene synthesis.

In another experiment in Petrolina-PE, Gomes et al. (2008) evaluated the performance of a biostimulant composed of citric biomass, citric bioflavonoids, ascorbic acid, citric phytoalexins, lactic acid, citric acid, polyphenols, vegetable glycerin, and organic acids applied during floral induction together with KNO_3 in ‘Tommy Atkins’ mango trees. They found that the biostimulant increased productivity by increasing the number of panicles on average by 40.16 per plant compared to the control.

Dash et al. (2021) evaluated the effects of applications with *Ascophyllum nodosum* (1000, 3000, and 5000 ppm), homobrassinolide (0.1, 0.3, and 0.5 ppm), and triacontanol (1, 3, and 5 ppm) during the flowering and early fruit development of the mango cultivar ‘Kesar’. These authors found that flowering intensity in treatments with homobrassinolide ranged from 67.64 to 70.37%, while for plants treated with *Ascophyllum nodosum* it was from 64.50 to 66.17%. They also reported that triacontanol (5 ppm) produced the longest and widest panicles (26.45 and 17.13 cm).

For 'Kent' mango grown in a semiarid region, Sanches (2020) studied the effects of different doses of triacontanol (0.0, 7.5, 15.0, 22.5, and 30.0 µL per plant) applied via foliar at branch maturation and floral induction. They observed an increase of 26.44% in the number of panicles, reaching 70.63 panicles per plant with an estimated dose of 23.62 µL melissyl alcohol per plant.

Lobo et al. (2019) studied the effect of several biostimulants sprayed between the end of floral induction and full bloom. They found that the biostimulant containing nutrients (nitric nitrogen 10.0%, potassium oxide 5.0%, calcium oxide 7.15%, magnesium oxide 1.2%, and boron 0.1%) and L-α amino acid (0.35%) promoted a 27.1% increase in panicle length, while treatments containing *Lithothamnium* seaweed extract reduced fruit abscission, promoting a 45.5% increase in fruit retention.

Mudo et al. (2020) assessed the effects of different branch maturation strategies using K sources (K_2SO_4 and K_2O) combined with a biostimulant composed of water-soluble K (12% KCl), organic carbon (9.87%), amino acids (20%), anionic surfactants, and yeast extract on ‘Tommy Atkins’ mango flowering in a semiarid region. Their results showed that initial biostimulant sprays (first, second, and third applications, and first and second applications) complemented until the fourth application with K_2SO_4, as well as biostimulant combined with K_2SO_4, had better results for the number of reproductive and undifferentiated shoots, with average of 7.7 reproductive shoots per m^2 canopy. Treatments containing KCl in place of K_2SO_4 showed a low performance for flowering.

Morales-Payan (2015) applied a biostimulant (14.4% free amino acids and 7% nitrogen) at 3L per hectare per application on 'Edward' mango trees in Puerto Rico. They observed an increase in the number of fruits by 18.1% compared to plants of the control treatment (without biostimulant), but no reduction in fruit average weight (Morales-Payan, 2015).

5. Conclusions

Mango flowering is affected by several factors related to climate and plant, including biochemical compounds.

Climatic differences between growing sites, both for temperature and rainfall, directly affect mango phenology. Such disparities can also alter the period for a suitable vegetative growth (hot temperatures, heavy rains) and for an optimal floral induction (cool temperatures, drought). Cultivation practices must be adapted to such local conditions to stimulate early vegetative growth and therefore promote high and regular production of mango fruits.

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