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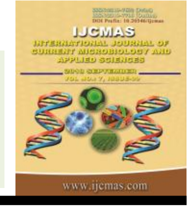

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Advances in Crop Regulation in Mango (*Mangifera indica* L.)

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A B S T R A C T

The Mango (*Mangifera indica* L.), member of family Anacardiaceae, is amongst the most important tropical fruit of the world. Flowering is the first of several events that set the stage for mango production each year. Flower initiation is very important because it is the first step towards attaining fruit and it is very complex phenomena in mango. Flowering in mango trees make them especially challenging for physiologists, breeders, and growers. Mango is a terminal bearing species and the factors which determine switching from vegetative to reproductive mode are poorly understood. Biennial bearing, which means that the tree carries optimum load of crop in one year, but in the following year it fails to flower or/ and produce unsatisfactory crop. Insight into this phenomenon has been of prime interest to scientists and growers for over a century. As a consequence of efforts to elucidate the factors governing flowering and mechanisms in manipulation of flowering in mango is critically reviewed here.

Keywords

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Introduction

Mango (*Mangifera indica* L.) member of family Anacardiaceae, in the order Sapindales with chromosomal number 2n=4x=40, is one of the most important tropical fruit of the world and is known as king of fruits (Purseglove, 1972). Mangoes are grown in more than 100 countries, both in the tropics and subtropics. India is the largest producer of mangoes with 20.5 million tons from 2.3 million hectares accounting for 21.7% of total fruit production (Anon, 2017). Although, India is the largest producer of mango, its productivity (7.3 tons/ha) is less as compared to the productivity of other mango producing countries because of conventional system of planting, alternate bearing habit, overcrowding of branches in the absence of proper canopy management resulting in poor penetration of sunlight, poor orchard management are some of the reasons for poor orchard productivity and poor fruit quality (Balamohan and Gopu, 2014). A better understanding of the nature of flowering induction in mango is necessary not only for yield sustainability but also for yield increase. Flower initiation is very important because it is the first step towards attaining fruit and it is very complex phenomena in mango. Flowering in mango trees make them especially challenging for physiologists, breeders, and growers. Mango is a terminal bearing species and the factors which determine switching from vegetative to reproductive mode are poorly understood. Biennial bearing, which means that the tree carries optimum load of crop in one year, but in the following year it fails to flower or/ and produce unsatisfactory crop. Biennial bearing, alternate bearing or cropping periodicity in mango cropping are synonyms.

Important factors governing flowering in mango

Environmental factors

Mango can be grown under a wide range of climate, particularly well adapted to tropical and subtropical climates and optimum temperature of 25 ^{0}C is needed for its optimum growth and productivity. The temperatures less than 10 ^{0}C or higher than 42 ^{0}C are not conducive for growth and development. Flowering is a decisive factor in the productivity of mango. The flowering process in mango involves shoot initiation followed by floral differentiation of apical bud and panicle emergence. All these developmental events occur in most of the mango cultivars during October-December under tropical as well as subtropical conditions. The flower bud formation has a strong link to prevailing environmental conditions like cool inductive temperatures in subtropical conditions and age of the terminal resting shoots under tropical conditions (Davenport, 2007). Climatic factors are associated with the biennial bearing of mango trees in 2 ways: *(i)* by damaging the crop directly by destroying the fruit bud, blossoms and fruits. Frost, high temperature accompanied by low humidity and hailstorm etc., or *(ii)* by creating conditions that indirectly affect the production of flower or fruit on the tree adversely. Cloudy weather and rains during blossoming period reduce the crop indirectly by creating favourable conditions for the spread of mango hoppers and of diseases such as powdery mildew and anthracnose. At times, severe attack of mango hopper, blossom blight or early spring frost destroys completely the fruit blossoms and this converts an 'on' year into an 'off year condition. The very fact that off-season cropping was possible at Kanyakumari in South India suggested that flowering in mango is certainly under the environmental control. The accumulating age of stems is greater in water stressed trees than the trees maintained under well watered condition. Chen *et al.,* (1999) reported that the temperature is considered to be key environmental factor, with low temperatures (19 ºC in day and 13ºC in night) favorable for fruit-bud-differentiation.

Growth pattern

Mango tree is characterized by strong phenological a synchronism within and between trees. In fact, the growth in Mango takes place in different flushes, which vary in different parts of the country. Early initiation and cessation of growth, followed by a definite dormant period, will help the shoots to attain proper physiological maturity, which is essential for fruit-bud initiation in them. The flushing refers to the emergence of new shoots on the terminals of old shoots. Generally a healthy mango shoot completes four to five flushing episodes per year depending upon cultivars and growing condition. The most important thing in case of flowering in mango is to produce new vegetative growth in the 'on' year which should also be mature to be ready to enter into reproduction phase and give out flower in following season. April flushes, which are considered to be the more productive may re-grow several times during the following months or may cease to grow anymore to attain blooming maturity and thus this becomes essential to determine pattern of growth of this flush. Moreover, induction of early flowering results in early maturity of the mango fruits which fetch the higher price in the market as compared to late maturing mango fruits.

Crop load

Even the regular- bearing types, if they carry a heavy load of crop in 1 year, show a tendency towards reduced yield in the following year. Hence the basic tendency of bienniality exists even in the so-called regular-bearing varieties of mango. The potential of shoot to form flower buds will depend on the floriferous condition of the tree, which in turn will be determined by the amount of fruit load carried by the tree in the previous year (Singh, 1971).Generally, moderate blossoming is one of the chief conditions of annual fruit bearing in fruit trees. Apparently, in mango the fruiting is an exhausting process.

The maximum available (30 leaves) on a single shoot could not support the growth of a single fruit to normal size in the 'on' year. Therefore the fruit development depended not only on current assimilates but also to a great extent on the reserve. The utilization of reserve metabolites from vegetative organs during the 'on' year could contribute to biennial or erratic bearing.

Nitrogen and carbohydrate reserves

In almost all the varieties studied, it was found that higher starch reserve, total carbohydrates and C: N ratio in the shoots favoured flower initiation in mango. Total nitrogen content was higher in the stem and leaves of trees which were expected to initiate flower buds irrespective of the varieties they belonged to. The available evidence indicates that nitrogen and carbohydrate reserves play an important role-if not the primary role-in flower-bud initiation. Perhaps the accumulation of these compounds may create a favourable condition for the synthesis and action of the substances actually responsible for flower induction in these plants. There was an increased accumulation and metabolism of carbohydrates, proteins and amino acids constituents in the mature plants compared with the juvenile plants (Davenport, 1997).

Hormonal control of flower formation

Developing vegetative shoots are rich sources of auxins and gibberellins. Elevated auxin synthesis in periodically flushing shoots is likely to form a concentrated pulse of auxin, which inhibits recurring bud break and moves basipetally to roots, this pulse of elevated auxin may stimulate initiation of new root flushes following each vegetative flush. New roots that develop following growth stimulation are a primary source of cytokinins. Cytokinins are transported passively to stems via the xylem sap in all plants and are active in bud break.

Leaf produced auxin and petiolar auxin transport capacity declines as leaves age. Auxin and cytokinins may therefore be involved in the periodic cycle of bud break. During a rest period, the inhibitory action of auxin transported to buds decrease with time; whereas, cytokinin level in buds increase.

When critical cytokinin/auxin ratio is achieved, the buds are stimulated to grow, thereby resetting the cycle with initiation of new shoots. Seeds are rich sources of auxin and gibberellins, which contribute to the strong inhibition of bud break commonly observed on fruit bearing mango stems. Water stress inhibits shoot initiation by interfering with translocation of cytokinins from roots. During water stress, roots continue to grow and produce cytokinins. Reduced xylem flux due to limited soil hydration, and transpiration due to increased stomatal resistance during water stress may reduce the amount of cytokinins reaching stems. After rewatering, the increased levels of cytokinins in roots may translocate to and accumulate in buds. Auxin synthesis and transport from leaves are reduced during water stress and may require several days for correction after rewatering.

This rapid shift in the cytokinin/auxin ratio of buds may explain the shooting response that occurs soon after relief of water stress. Mango trees flush often and synchronously throughout the canopy when they are young. With advancing age, the frequency of flushing is reduced and synchrony is lost, resulting in sporadic flushes of vegetative or reproductive growth in sections of the canopy. As the distance between stems and roots increase, the time required for transport of the putative pulses of elevated auxin levels to roots, formed during a vegetative flush, is increased.

Varietal character

Most of the commercial varieties of mango show the same pattern of bearing (biennial); but 'Baramasi' may exhibit erratic and off-season bearing; and 'Totapari Red Small', 'Neelum' and 'Bangalora', show distinct regularity. Some varieties, though excellent in fruit quality, are shy-bearing such as 'AllampurBeneshan' and 'Himayuddin' of south India.

Regulation measures

Biennially bearing mango cultivars usually do not flower during off year even under low temperature conditions. Few methods for manipulating of mango flowering alternative to environmental cues are discussed here.

Smudging

Smudging is an early commercial method of inducing mango to flower (Wester, 1920). Gonzales (1923) considered only mature shoots of 1 year or older with very brittle, dull grayish green to copper coloured leaves and plump terminal buds are suitable for smudging. It is practiced in certain parts of the Philippines to obtain earlier and increased flowering of 'Carabao' and 'Pico' mango. Ethylene has been identified as the active agent responsible for flowering during smudging (Dutcher, 1972). Smudging is done continuously for several days and is stopped if flower buds do not appear within two weeks. The process may be repeated 1-2months later. According to Sen and Mallik (1947) Experiments were conducted at the Fruit Research Station, Sabour, India with the Langra mango in order to study the effect of smudging treatment on the plant under the local conditions. It is apparent that smudging has a stimulating effect on growth, but the nature of growth, reproductive or vegetative, depends on other factors and concluded that smudging can induce flowering only if the shoot is in condition to flower.

Deblossoming

Deblossoming is a more severe form of fruit thinning, employed to conserve the reserves of the shoots which could otherwise be depleted later on in the development of fruits. Thus the deblossomed tree, instead of developing panicles and producing fruits, puts on new vegetative growth in mango, which flowers and fruits the next year. Partial defloration is important in regulating the crop, since excessive fruiting during 1 year brings about biennial bearing in the mature mango trees. The partial or complete removal of flowers in the 'on' year increases flowering the next year.

Pruning

In perennial fruit crops like mango, pruning is unavoidable necessity to control the canopy size and to produce high quality marketable fruits by facilitating better ventilation, high penetration of sunlight, easy application of plant protection chemicals and ease in harvesting (Burondkar *et al.*, (1997), Gross (1996)). Pruning in mango has two important goals like encouraging the branching of young trees particularly in cultivars which do not branch readily on their own, stimulating the development of new shoots and maintaining the tree size (Oosthuyse, 1994). Juvenile trees do not flower due to short intervals between vegetative flushes. Normally mango tree takes three to four years to reduce the flushing frequency and sufficient stem maturity there by allowing flowering and to produce a commercially viable crop. Tip pruning forces a synchronized flush from pruned stems, which results in synchronized flowering in Keitt mango (Davenport, 2006). At harvesting, if the fruits are plucked along with the panicle, light pruning is effected automatically and the tree could send forth, from the distal lateral buds.

The age of the last flush is the dominant factor regulating flowering of mango. Stems must be generally about 4 to 5 months to be able to induce for flowering in the next year (Davenport, 2003). Pruning is effective for early and higher accumulation of reserves by enhancing uniform post-harvest flushing and reduce flowering variation (Oosthuyse, 1994). Dashehari mango produced the maximum number of panicles in July pruned trees (Swaroop *et al.*, 2001). Moderate pruning and spraying with GA_3 at 100ppm, is promising for mango since it increased length of new flushes, panicle length and improved yield of Zebda mango trees in the off-year season (Shaban, 2009).

Floral manipulation in mango by application of exogenous plant hormones

Ethylene spray

The ethylene-generating agent, Ethephon, (2-chloroethyl phosphonic acid) applied at 125-200 ppm, induced flowering of ‘Carabao' mango in the Philippines within six weeks after treatment (Dutcher, 1972). Ethephonhas also been successful in India for increasing flowering of 'Langra and 'Deshehari' during off' years (Chadha and Pal, 1986).

Cytokinins spray (6-Benzyl amino purine, 6-BA)

Chen (1987) described precocious bud break and flowering of mango shoots in response to an early October application of 100 ppm 6-Benzyl amino purine (6-BA).

Application of Paclobutrazol (PBZ)

Triazole plant growth regulators such as diclobutrazol, uniconazol, hexaconazol, propiconazol and paclobutrazolare class B plant growth regulators that act as anti-gibberellin compounds by inhibiting the biosynthetic pathway of gibberellins. Triazoles also induce a variety of other responses in plants including reduced or altered sterol biosynthesis and increased chlorophyll concentration, increased photosynthetic rate, delayed senescence and increased stress tolerance (Zhu *et al.*, 2004).There are enough evidences that to show that, the isoprenoid pathway associated with gibberellin biosynthesis also regulates partially the biosynthesis of other vital phytohormones such as Abscisic acid (ABA) and Cytokinins (Upreti *et al.,* 2013).

Davenport and Nunez-Elisea (1997) elaborated that unlike the other classes of retardants that are normally applied as foliar spray, PBZ is usually applied to the soil due to its low solubility and long residual activity. PBZ is taken up through roots and transported through xylem to the stem and accumulates in the leaves and fruits. Early and intense flowering induced by PBZ may be the consequence of early shoot maturity and increased photosynthesis rate, carbohydrate accumulation and decline in flowering reducing hormone, gibberellins (Upreti *et al.*, 2013). The paclobutrazol induced enhancement in C: N ratio has been reported in mango consistently higher production of total sugars and reducing sugars with peak availability at bud burst in apical buds of paclobutrazol treated trees is reported in mango (Upreti *et al.,* 2014). Starch is one of the basic reserves of carbohydrates and its direct role in flower induction of mango.

Besides reducing the gibberellin biosynthesis, PBZ enhances the ABA content. PBZ induced increase in ABA content could be due to the modification in the isoprenoid pathway which is common for ABA and gibberellin biosynthesis (Upreti *et al.,* 2013). Paclobutrazol application in mango cv. Totapuri helps increase fruit weight and produces fruits with high-quality attributes viz., a high content of sugars, ascorbic acid and carotenoids. Pruning of trees to current season’s growth and PBZ application were vital for regulating tree size, early flowering and advancing fruit harvest in mango and such beneficial effects of treatments were mediated through increases in ABA and decreases in GA_3 contents (Srilatha *et al.,* 2015). PBZ application increases the percentage of flowering and also improves the fruit retention capacity of the trees (Vijaykrishna *et al.,* 2016).

Potassium nitrate spray

KNO_3 can enhance flowering especially in tropical regions where cold temperature for floral induction may not be sufficient. Flowering was evident within seven days after treatment and was effective on shoots that were between 4.5 and 8.5 months old when treated. The treatment was effective for stimulating flowering of trees that had remained vegetative well beyond normal bearing ages, for advancing the flowering and fruiting periods, and for breaking the biennial bearing habits of trees. Potassium nitrate is currently recommended in the Philippines for inducing uniform flowering and for the production of off-season fruits in the 'Pico' and 'Carabao' cultivars (Madamba, 1978). Concentrations of 2 percent ammonium nitrate were sufficient to promote early flowering in 'Haden', 'Tommy Atkins', 'Kent', 'Diplomatico' and 'Manila'. The similar results between ammonium and potassium nitrate indicate that the nitrate ion is the active portion of the molecule.

Davenport (2003) reported that bud break was initiated three months later by a foliar application of KNO_3 in weakly inductive condition (during warm temperature condition) maximum response was observed at about four weeks. Nutrients (KNO_3, $NH4NO_3$) when used as a foliar spray are more effective in induction of post-harvest early and profuse vegetative growth as well as early induction of flowering with increase in yield (Patil *et al.*, 2013). Spraying the ‘Apple’ and ‘Ngowe’ mango trees with 4% KNO_3 was found to be beneficial for all the flowering and fruiting parameters (Maloba *et al.,* 2017).
It is apparent that floral initiation in trees is

controlled by a range of factors which may include environmental stimuli, developmental cues, and other interactions with vegetative growth and PGRs. It is also apparent that rarely can one factor be considered in isolation. High level of starch, some auxin-like regulators and inhibitors and a low level of gibberellins may be seemed favourable for flowering in shoots. Crop regulation in mango is necessary not only for yield sustainability but also for yield increase. Use of plant growth regulator (paclobutrazol), shoot pruning and use of fruit set chemicals are found to be the most promising approaches for ensuring flowering and enhancing fruit yield under commercial cultivation.

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