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Role of Plant Growth Hormones in Cashew: Key Strategy for Modifying Crop Performance

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A B S T R A C T

Cashew (*Anacardium occidentale L.*) is an important tropical nut crop of social and economic importance worldwide. World's total area under cashew cultivation is around 35100 km^2. Despite the economic importance of cashew with increasing cultivation globally, the crop is threatened with the problems of low yield with world's average raw cashew nut yield is as low as 780 kg ha^{-1}. The present low productivity is due to establishment of plantation with seedling of non-descript origin, poor and irregular flowering, poor fruit set and premature fruit drop, low hermaphrodite flowers, inefficient pollination and nutritional deficiency etc. Plant growth hormones are gaining its importance for managing canopy, ensuring uniform flowering and enhancing fruit retention and yield under commercial cultivation for perennial fruit trees including cashew. Despite the importance of growth hormones to increase yield, their uses on cashew are limited despite daunting production challenges. In this review, we focus to understand how the endogenous hormones regulate the stages of plant growth in order to make exogenously applied plant growth hormones to play an important role in maximizing cashew nut yield. Although little works on effect of hormones existed in cashew, we show that cashew yield can be maximized through hormones by overcoming problems associated with plant growth, fruit set and final retention.

Introduction

Cashew (*Anacardium occidentale L.*) is an important tropical nut crop of social and economic importance worldwide. In current global scenario, major cashew production is concentrated in countries such as Vietnam, India, Nigeria, Brazil and Indonesia with annual raw nut production of 1,190,600 t, 665,000 t, 660,000 t, 147,629 t and 122,000 t respectively (FAO, 2008). World's total area under the cultivation of cashew is around 35100 km^2 with India sharing 20 percent and 16 percent of cashew area and production globally. Cashew is primarily grown for its kernel being highly nutritive and low cholesterol content. Other commercial and economic benefits of cashew include value added products such as juice, wine, vinegar, jam, pickle and cashew nut and shell liquid (CNSL) for industrial uses. In spite of economic importance of cashew as commodity and export oriented crop with increasing cultivation globally, world's average raw cashew nut yield is as low as 780 kg ha^{-1} (FAO, 2008).

Cashew is an evergreen dicotyledonous woody tropical tree with medium canopy size. On an average the plant attains 5-8 m height. The leaves are alternate, simple, glabrous, oblong, leathery, often notched at the apex. The size of leaf varies from 6 -24 cm in length and 4-15 cm in width based on species and variety. The root system of complete grown cashew tree consists of a taproot surrounded by a well developed and extensive network of lateral roots, 90% which lie on the 15-32 cm soil depth. The pattern of growth of cashew tree alternates with vegetative and reproductive phases. There are two types of branching in cashew intensive and extensive type (Damodaran, 1965). Intensive type of growth pattern tends to give bushy appearance to tree whereas extensive type results in spreading tree habit. Annually, two or three peak periods of growth are observed in bearing cashew tree with development of stray shoot growth. In bearing trees, from flower flush many shoots develop that give rise to terminal inflorescence/ panicle. The other vegetative flush gives rise to lateral shoots that develop soon after main crop has matured.

The cashew flowers are pentamerous, white or light green at the time of opening, later turn to pink. Two kinds of flowers viz. hermaphrodite (bisexual/perfect) and male (staminate) are present in the panicle. The perfect flowers are larger than staminate flowers (Damodaran *et al.*, 1965). Cashew is considered as andromonoecious species due to presence of both male (staminate) and hermaphrodite (perfect) flowers in the same terminal panicle usually called as inflorescence of cashew. Number of panicles per plant, flowers per panicle and distribution of male and hermaphrodite flowers (sex ratio) in each panicle vary among varieties. In flowering panicle, abundance of male flowers is reported higher than perfect flowers. These results are consistent with findings from Rao and Hassan (1957); Bigger (1990) and Damodaran *et al.*, (1966). The cashew produces abundant flowers but only less than 10 per cent of which are hermaphrodite, about 85 per cent of the hermaphrodite flowers are fertilized and only 4-6 per cent of them reach maturity to give fruits, the remaining shed away at different stages of development. The fruit drop in cashew during the early stages of development is attributed to physiological reasons (Nothwood, 1966). Immature fruit drop is one of major reason for reducing yield potential of cashew.

The formative effects of growth hormones is gaining its importance for managing canopy, ensuring uniform flowering and enhancing fruit retention and yield under commercial cultivation for perennial fruit trees including cashew (Olivier *et al.*, 1990). The application of exogenous plant growth hormones has been reported to induce better root and shoot development, to break seed and bud dormancy and improve flowering and fruiting in many crop plants. Foliar spray of gibberellic acid and auxin increased shoot and root growth and total shoot and root biomass in treated cashew seedlings (Shanmugavelu, 1985). The better seed germination induced by GA in cashew has also been reported by Khan *et al.*, (1957), Barton *et al.*, (1957). Shanmugavelu *et al.*, (1985) suggested that the seeds of tree species contained natural auxin which might probably regulate the seed germination. The use of cytokinin and auxin improved flowering and fruit set in mango (Chen, 1983) and cashew (Kumar, 1994). Therefore, growth hormones are gaining importance in cashew cultivation for overcoming problems associated with rooting, flowering, fruit set, fruit retention and poor yield. Hence, it is evident from studies that the economic importance of hormones is their ability to increase nut yield. There have been numerous reports considering increased yield due to the use of hormones especially in the horticultural sector but the use of plant growth regulators on cashew in particular is in its infancy. Hence, it is of the utmost importance to address this research gap and it is also essential to understand how the endogenous hormones affect or regulate the stages of plant growth in order to make exogenously applied plant growth hormones to play an important role in maximizing cashew nut yield. Here we discuss the influence of plant growth regulators on overall performance of cashew tree from available studies.

Effects of plant growth hormones in Cashew

Dormancy and seed germination

The most important functions of plant hormones are controlling and coordinating cell division, growth and differentiation (Hooley, 1994). Plant hormones can affect different plant activities including seed dormancy and germination. Seed germination and dormancy are important processes affecting plant overall performance. These processes are influenced by a range of factors, including plant hormones. The plant hormones, including ABA, IAA, cytokinins, ethylene, gibberellins and brassinosteroids, can positively or adversely affect seed germination, while interacting with each other. Germination rate (speed of germination) can be used as tool in breeding programme for evaluation of seedling vigor.

In cashew, Shanmugavelu *et al.,* (1970) reported the effect of plant growth regulators on nut germination. Studies revealed that GA_3 induced better nut germination in cashew than other chemicals. They suggested that nuts of cashew contained natural IAA which might probably regulate seed germination. They also reported that chlorophenoxy acetic acid (CIPA) caused inhibition of germination which might be due to chemical interference with inherent auxin- kinin or auxin-gibberellins balance in seeds. Similar results were also reported by Laxmipathy *et al.,* (2014) where studies revealed that application of 200 ppm GA_3 was mainly attributed to enhanced germination, early seedling emergence, highest vigor index and better seedling growth in cashew. Oblisami *et al.,* (1985) reported the influence of *Azotobacter* inoculants and growth regulators on seed germination in cashew. They found that maximum percentage of germination of the cashew nut was recorded in water soaked control (92%) followed by *Azotobacter* plus GA (87%). The treatments *Azotobacter* alone and IAA had same effect on germination.

Regulation of seedling and root growth

Cashew is highly heterozygous in nature due to cross pollination. Hence seedlings propagated through nuts exhibit wide genetic variation among cross pollinated progenies resulting in poor yield. Therefore, vegetative propagation offers opportunity in maintenance of desired characteristics of mother tree and hence it becomes the preferred choice for raising cashew propagules (Oliveria *et al.,* 1989). In cashew, poor rooting of propagules is major concern which hampers usefulness of large scale cashew planting programme. The preliminary works done by Aliyu *et al.,* (2007) showed that 65% air layered plants sprouted and less than 8% survived after transplanting. Further detailed studies by Aliyu *et al.,* (2007) revealed that most of layers only callused and failed to root. These studies clearly indicate that root initiation is very poor in cashew layers.

Cashew is commercially propagated through soft wood grafting where early attainability of seedling height can reduce the cycle of propagation. Young seedlings of cashew usually do not produce lengthy tap root and secondary roots and hence seedlings suffer heavy causalities especially during summer. Among plant hormones, auxins have been reported to facilitate stem growth, adventitious root growth and activation of cambial cells (Went, 1934). Aliyu *et al.,* (2010) reported that auxins significantly improved rooting in terms of layer take, number of roots per layer, number of days to rooting, root length and percentage of survival after transplanting. The possibility of inducing better root and shoot development by treating cashew seeds or seedlings with plant growth regulators to reduce mortality was also investigated by Shanmugavelu and Rangasawamy *et al.,* (1970). They reported that 500 ppm GA treatment resulted in 77% higher shoot growth but failed to induce root growth which were consistent with studies reported by Sumiki (1952) and Brain *et al.,* (1955) reporting GA as negative regulator of root growth. Auxins like NAA at 100 ppm and 500 ppm recorded 92% higher root growth and production of secondary roots in cashew seedlings where as GA_3 did not influence the production of secondary roots of cashew. Rao and Hassan (1957) reported that no lateral roots could be seen in case of one or two month old seedlings of cashew but studies by Shanmugavelu and Rangasawamy *et al.,* (1970) showed the induction of roots when seed or seedlings are treated with plant growth regulators. GA treatments also resulted in increased shoot and root biomass in cashew seedlings focusing its role in cell elongation and increase in cell number (Brain *et al.,* 1959). The most striking response of GA on cashew is the stem elongation. The number and length of cells in the cortex and pith regions were influenced by GA treatment. Therefore, it appears that stem elongation is predominantly due to cell elongation supplemented with cell division in the cortex and pith region which supports the work of Stowe and Tamaki (1957). In cashew increase in fresh and dry weight of shoots and roots can be attributed to increase in the overall assimilation and redistribution of materials within the plants.

Oblisami *et al.,* (1985) studied the effect of *Azotobacter* and growth hormones on growth of cashew under pot culture experiment. They found that *Azotobacter* inoculants alone caused better growth of the root system and among the plant growth regulators GA induced better root growth over IAA. The better root formation by GA is in conformity with earlier works by Richardson, (1958) and Shanmugavelu, (1969) with different plant species. Better root growth of the cashew seedlings due to *Azotobacter* inoculants is in agreement with the earlier reports by Brown (1974). Combination of *Azotobacter* and GA induced better lateral root growth in early phases of plant development. This may be due to the fact that *Azotobacter* is known to synthesise growth promoting compounds like IAA, GA and GA like sunstances and releases into environment. This might be responsible for the better root development. Treatments combining *Azotobacter* with IAA and GA induced better shoot growth and this might be probably because of synthesis and excretion of IAA and GA in the root zone as reported by Brown, (1974) in various other crops.

Propagation

Cashew is a cross pollinated crop and therefore, the seedling progenies obtained through seed propagation are heterogeneous due to segregation. Conventional vegetative propagation methods such as air layering, mound strolling, or cutting have been attempted in cashew but the multiplication rate is inadequate to meet ever increasing requirement. However, the performance of this crop obtained through conventional vegetative propagation methods is poor and breeding desirable plant traits has also become difficult due to its out-breeding nature. Hence, in order to accelerate success in plant propagation, alternative propagation methods have been attempted and among them *in vitro* propagation is an effective method for large scale clonal multiplication of tree crops like cashew compared to conventional methods (Mott, 1981; Rao and Lee, 1982; Bajaj, 1986; Fiorino and Loreti, 1987; Mascarenhas and Muralidharan, 1989). Even though *in vitro* propagation method has been successfully attempted in other *Anacardiaceae* (Mango, Pictachio) (Litz *et al.*, 1984; Martinelli, 1988), only limited success has been achieved in case of cashew (Philip, 1984; Jha, 1988; Lievens *et al.*, 1989). Micro propagation method results in faster multiplication and building up the clonal stock of elite genotypes. *In vitro* propagation from mature plant tissues (nodal segments or shoot apices) was found difficult in cashew due to its recalcitrant nature, microbial contaminations and high phenolic content. Therefore, *In vitro* somatic embryogenesis potentially offers alternative forms of large scale propagation of plants. Yet attempt to induce somatic embryogenesis in cashew from immature embryos (Jha, 1988) and immature cotyledons (Hegde *et al.*, 1994) met with limited success.

Types and concentrations of plant growth regulators used in culture media play crucial roles in the induction of *in vitro* organogenesis, because cashew is a hard-rooter (D'Silva and D'Souza, 1992). Studies by Ananthakrishnan *et al.*, (1999) reported induction of somatic embryogenesis from nucellus-derived callus of cashew when supplemented with 4.52 mM 2,4-D. Further studies on the ontogeny of somatic embryos showed that the cells destined to become somatic embryos divided into spherical or filamentous pro-embryos. Subsequent divisions in the pro-embryo led to globular, heart and torpedo stages of somatic embryos. There was no further development of the torpedo stage in the liquid medium containing 2,4-D. Bavatharine *et al.,* (2010) confirmed the development of somatic embryoids directly from cultured cotyledon explants when cultured on MS basal medium containing various concentrations (0-10 mg/litre) of BAP (benzyl amino purine). MS medium with 8 mg/litre BAP was the most optimal concentration for the induction of somatic embryos among tested. Studies by Kamshananthi *et al.*, (2012) reported 80% higher nodule induction in cotyledon explants in MS medium with 2 mg/litre of BAP and 40% higher root formation with 2 mg/litre Kinetin and NAA (Naphthalene acetic acid). Further, it was also noticed that medium which contained 2mg/ litre BAP showed higher percent of somatic embryoid formation directly from cotyledon explants. In addition, Thimmappaiah *et al.*, (2002) noticed that a repeatable auxillary shoot bud induction in cashew was obtained on MS medium with 2.74 mM L-glutamine, 87.6 mM sucrose containing thidiazuron (TDZ) alone and in combination with BA (benzyl adenine). TDZ at 0.45 µM was best for auxillary shoot bud proliferation (4.5 buds per shoot) with maximum response (100%). Further it was found that *in vitro* rooting on auxin media and pulsing micro shoots in 10 mM NAA was ineffective.

Control of plant growth

The improvements in over all plant performance including plant productivity are largely dependent on manipulation of physiological mechanisms by chemical means. Trees and shrubs often grow too large for the available space. In the past, costly mechanical trimming was the sole method available to reduce tree and shrub size. Consequently, chemical growth retardants were developed as an inexpensive approach to limit size and the growth rate of trees. Cashew is a fast growing woody perennial, covers the allotted space under high density planting, within a short span of 6-7 years. Controlling excessive vegetative growth for increased or sustained productivity is the major principle of high density planting (Santram, 1996). In cashew, due to non availability of dwarf clones, dwarfing root stocks or a pruning technology for the management of vigorous canopies, use of growth retarding chemicals assumes significance. The first major breakthrough in the commercial feasibility of tree growth retardants (TGRs) on a large scale was the formulation in the late 1970s of the cell elongation inhibitors, paclobutrazol, uniconazole, and flurprimidol for trunk injection. Paclobutrazol is more potent than most other growth retardants and relatively low rates are required to inhibit shoot growth. The most pronounced effect of paclobutrazol on plant is the reduction in height, with the treated plant being greener and more compact. The plant becomes greener due to increased chlorophyll content per unit leaf area.

Reduction in shoot growth by Paclobutrazol (PBZ) occurs primarily as a consequence of reduced internode elongation. Treatments with like Paclobutrazol was found effective in reducing the growth of fruit crops like pear, peach, lemon, apple, litchi, apricot, plum and mango. Misra and Singh, (1991) found that reduction in growth was observed in cashew when Paclobutrazol was applied to young grafted plants at nursery stage. Application of 50 ppm PBZ as soil drench could restrict vegetative growth up to six months. The growth of tap root was reduced while lateral root growth was increased. Treated cashew grafts when planted in field showed normal growth. Studies conducted by R K Meena *et al.,* (2014) reported the regulation of growth and yield of cashew varieties by PBZ application when applied @ 1, 2 and 3 *a.i.* per plant as soil drench. They found that the application of PBZ reduced plant height, canopy spread and intermodal length. The application of PBZ at pre-flushing stage was effective in increasing number of flushes with yield increment up to 51.78 %.

Influence on leaf area and photosynthesis

Among various determinants of crop yield, plant leaf area plays significant role in influencing light interception, transpiration, photosynthesis and plant productivity (Goudriaan and Van Laar, 1994). In cashew, the fruit set and development is dependent on irradiance and the adaption of leaf to shade is minimum (Subbaiah, 1984). Lakshmipathi *et al.,* (2014) reported that application of GA_3 @ 50 ppm and Ethrel @ 50 ppm recorded maximum leaf area. Similar kind of results was also reported by Wahdan *et al.,* (2011) in mango. This increase in leaf area with GA_3 might be related to the fact that GA promote leaf area through the increase of cell division in higher plant (Hartmann *et al.,* 2002; Hopkins and Huner, 2004; Harris *et al.,* 2004). Higher leaf area values recorded with Ethrel and GA_3 may be due to increased concentrations of photosynthesis in the shoot (Nunez *et al.,* 1998; Zofoli *et al.,* 2009 and Zahoor *et al.,* 2011) as reported in grape.

In agricultural crop system, any breakthrough in productivity has to come by improving the physiological efficiency of the plants in terms of photosynthesis, partitioning of photo-assimilates, improved biophysical characteristics and several other metabolic reactions, which are linked by numerous interactions ultimately leading to productivity. Plant growth regulators have been shown to influence these processes in one way or the other. Lakshmipathi *et al.,* (2014) reported that exogenous application of GA_3 @ 50 ppm and Ethrel @ 50 ppm recorded maximum net photosynthetic rate (P_N) and stomatal conductance (g_s) in cashew. They also reported that timings and quadrants of the canopy had significant influence on photosynthetic rate and stomatal conductance.

These findings were consistent with Farquhar and Sharkey, (1982) who reported that at low PAR, the P_N is reduced and stomata partly closed, impose less limitation on P_N (Caemmerer and Farquhar, 1981). Studies on exogenous application of plant growth regulators on photosynthetic activity of cashew varieties indicated that PAR and LA are positively correlated with yield indicating their importance in yield enhancement in cashew (Lakshmipathi *et al.,* 2014).

Sex ratio, flowering and fruiting

Flowering in cashew is seasonal and produces innumerable flowers but only 1-2 per cent of the flowers set fruit and reach maturity. Production of more number of pistillate flowers and reduction in nut drop can be accomplished by the use of plant hormones. It has been reported that foliar sprays of Gibberellic acid (GA_3), 1- Naphthalene acetic acid (NAA) and Ethylene increased the production of perfect flowers and improved sex ratio in cashew (Puhual *et al.,* 1993; Kumar *et al.,* 1995; Aliyu *et al.,* 2011). Gawankar *et al.,* (2010) opined that cashew trees sprayed with 50 ppm Ethrel had significantly the highest number of flowering panicles per square, number of perfect flowers per panicle and sex ratio. Ethylene is believed to be the chemical which causes natural initiation of flowering. It can also be attributed to an increase in the activity of peroxidase and α-amylase which ultimately released more sugar for induction of flowering (Yamdagni and Khangia, 1989). A significant increase in the number of flowering panicles per square meter with Ethrel 50 ppm in case of Bhaskara was reported by Lakshmipathi *et al.,* (2014). They also reported improvement in sex ratio by foliar application of Ethrel at pre- bloom stage. Gawankar *et al.,* (2010) indicated that the number of staminate flowers was related to the number of lateral per square meter. Higher number of laterals in water sprayed trees could have resulted in higher number of staminate flowers. Singh *et al.,* (1992) reported that foliar application of Ethrel @ 100 ppm increased the number of perfect flowers in cashew.

Improvement in the sex ratio with the application of Ethrel was mainly due to increased number of perfect flowers. Ethrel may also have exerted its effect on sex expression by manipulating endogenous auxin levels corresponding to a reduction in staminate flowers as reported by Mariappan *et al.,* (1995). Kumar *et al.,* (1996) reported that number of perfect flowers per panicle was positively correlated with yield in cashew. A similar correlation was observed by Lenka *et al.,* (2001). Dorajeerao *et al.,* (2001) reported that clones having broader sex ration were high yielder.

Fruit set and their retention are the major limiting factors for low yield in cashew which needs due attention. The nuts that develop after pollination start drying followed by dropping, leading to very low percentage of matured nuts. Use of growth regulators like auxins, gibberellins, and ethylene has resulted in improving the vegetative and reproductive parameters which are associated with high yield in many fruit crops (Lafer, 2008; Chacko *et al.,* 1974; Rawash *et al.,* 1983; Singh *et al.,* 1986). Preliminary studies carried out on improvement of sex ratio, fruit set, fruit retention and yield by use of growth regulators have indicated beneficial effects in cashew. Increase in the percentage of fruit set by 55 per cent in cashew with foliar application of 10 ppm NAA was reported by Murthy *et al.,* (1975). Lashmipathy *et al.,* (2014) reported that spraying of 50 ppm Ethrel increased the number of fruits set, number of fruits retained per panicle, nut weight (g), nut yield (kg) per tree and reduced fruit drop per panicle in cashew. Increased fruit set and fruit retention due to application of Ethrel and other growth regulators could be attributed to the increased number of bisexual flowers and reduced pre mature fruit drop. Similar findings were also reported by Singh *et al.,* (1986) in mango. Fruit drop, an abscission phenomenon, often occurs due to auxin deficiency in growing fruits and could be prevented by the exogenous application of synthetic auxins such as NAA and 2,4-D. Reduced fruit drop due to exogenous applications of growth regulators may be attributed to increased endogenous auxins which helps in overcoming the formation of abscission layer in the abscission zone, thereby reducing the immature fruit drop and increasing mobilization of nutrients to the developing fruit (Salisbury and Ross, 1986; Kumar *et al.,* 1994). Reduced fruit drop in cashew due to application of growth regulators was also reported by Konhar and Arun Mech, (1988). Aliyu *et al.,* (2011) found that highest fruit set and improvement in fruit retention was recorded from twigs treated with GA_3.

This remarkable response in cashew twigs treated with GA_3 over other exogenous hormones suggests hormone-specific nature of cashew tree (Davenport, 2003). But it was surprising that none of treated twigs successfully retained 100% of fruit set despite improvement in fruit retention ability of the treated twigs. This observation corroborated studies on the complexity of factors controlling yield and role of nutrition to fruit development and retention in cashew (Aliyu, 2008). Such studies correspond to role of GA_3 to enhance photosynthetic production through an efficient use of nitrogen N (Khan *et al.,* 2004). Thus it is evident that upper limit regulatory mechanism and compensatory effect of the number of fruits vs. weight of fruit per tree will continue to play a significant role in cashew tree productivity (Aliyu, 2011).

Influence on nut yield

Correlation analysis for yield attributing characters using different plant parameters has been attempted by several workers. Nut yield (kg) per tree was found to be most significantly and positively correlated with number of flowering laterals per square meter, total number of laterals per square meter, duration of male flowers, duration of hermaphrodite flowers, number of male flowers per panicle, number of hermaphrodite flowers per panicle, total number of flowers, number of fruits set per panicle, number of fruits retention per panicle and nut weight (Lashmipathy *et al.,* 2014 and Kumar *et al.,* 1996). Similar correlation was also reported by Lenka *et al.,* (2001).

Among the various factors influencing cashew yield, the narrow sex ratio is of primary importance. Therefore, growth regulators are gaining importance in cashew cultivation for overcoming problems associated with fruit set, development and, final retention. Improvement in sex ratio with application of growth regulators was mainly due to increased number of bisexual flowers. Both auxin and ethrel had stimulating effect on the physiological changes in the tissues influencing the flowering characters (Salisbury and Ross, 1986). The increase in length and number of secondary branches per panicle are important attributes for the production of more number of flowers which increases the yield. The flowering in other fruit crop as influenced by ethrel and auxin was also reported by Chacko *et al.,* (1974) and Rawash *et al.,* (1983) in mango. Increased nut yield by Ethrel application has been reported in cashew by Mohan and Rao, (1995); Gajbhiye *et al.,* (2007); Gawankar *et al.,* (2010) and Lashmipathy *et al.,* (2014). Increased nut yield with application of growth regulators could be attributed to increased number of bisexual flowers, fruit set, fruit retention and total number of nuts per tree (Veeraragha vathatham and Palaniswamy, 1983). Aliyu *et al.,* (2011) showed that application of exogenous hormones can improve fruiting/yield significantly through the flowering components (Days to flowering and Hermaphrodite flowers per panicle) in cashew. Kurian and Iyer (1993) reported similar yield increase through intense flowering in mango trees sprayed with cytokinin-based plant growth regulators. The significant reduction in the period of flowering will considerably enhance flowering synchronization in cashew. These two events coupled with the increased number of hermaphrodite flowers were likely responsible for higher fruit set through improved pollination.

PBZ has been reported to exert influence on partioning the photosynthates to the sites of flowering and fruit production consequent to the reduction of vegetative growth. In this context, Meena *et al.,* (2014) reported that PBZ treatment increased nut yield per plant but nut length, width, weight and volume decreased. The maximum yield increment of treated plants (51.7%) was associated with PBZ @ 2.0 *a.i*. per plant. A significantly higher fruit set and fruit retention in PBZ treated plants had favourable impact on culminating higher nut yield per plant.

Influence on nutritional value

Cashew is of considerable economic importance due to various economic uses of its components. Cashew apple is used as an important ingredient in the production of cashew beverages while cashew kernel is of high food value with 40-57% oil and 20% protein content. Studies on the influence of plant growth regulators and nutrients on nutritional quality in cashew are meagre and limited. However, published studies indicated that the application of PGR and nutrients had marked influence on apple weight, quality, yield and juice content of the cashew apple. Kumar *et al.,* (1996) studied the effects of different levels of NPK nutrients and plant growth regulators on apple quality and yield in cashew varieties. They found that combined application of ethrel @50 ppm and 500: 250: 250 g NPK/plant/year was most effective treatment. The combined application showed decrease in weight and juice content of apple which might be due to increase in the number of fruits per panicle. There was considerable increase in total soluble solids and apple yield which might be attributed to the positive interaction between growth regulators and nutrients.

Gibberellins are known to influence certain environmental factors for flowering in large number of plant species (Krishnamurthy, 1975). Exogenous application of GA_3 in plant species resulted in increase in fruit set and decrease in fruit drop resulting in higher yields (Moore *et al.,* 1975; Valdovinos, 1975). Murthy *et al.,* (1975) on the other hand found that GA_3 has little effect on cashew. There have been studies of the levels of GA_3 and seed development in different plants (Skene *et al.,* 1961; Ogawa, 1963) but there is scanty information on the GA_3 induced changes of free amino acid and total protein during development of cashew kernel.

M. Hariharan *et al.,* (1979) studied the free amino acid and total protein content in three developing stages of kernel in cashew after foliar treatment with 40 ppm and 50 ppm gibberellic acid. They found that the effects of GA_3 on free amino acid and protein content vary according to concentrations of hormone used but does not follow uniform pattern. In GA_3 treated cashew kernels, the amino acid contents show progressive decrease with the growth and maturation of the nut and greater accumulation of protein. Cystein which is absent in the control samples at all stages, is abundant in the treated samples. But hydroxyl proline content was completely disappeared in treated samples. Treatment with GA_3 results in a marked increase in protein content of kernel at all stages of development. The onset of marked storage protein synthesis commences in the early phase itself under the influence of GA_3 treatment in contrast to control.

Hence concluded that the ways in which plants transport and regulate both local and long distance hormone based signals are important research targets. Similarly, the mechanisms by which these signals are translated into plant responses such as changes in plant architecture and biomass, changes in plant water transport, gas exchange and yield related parameters need extensive studies to understand the complexity between hormonal balance and plant performance. Such knowledge can impart greater influence on screening cashew varieties with desired agronomic and plant traits and can allow the development of novel ways of managing cashew trees in the field. The research in this direction is important in the context of food security because the traditional or conventional breeding for yield trait is both slow and complex. However, determining the important phenotypic trait that could act as yield surrogate for yield requires in depth knowledge.

Plant architecture, reproduction capacity and tolerance to various abiotic stresses are among the agronomically important traits controlled by plant growth hormones. Given the importance of growth hormones in these processes, engineering their biosynthetic and signaling pathways offer wide potentials for enhancing yield in cashew. To date, information on plant growth hormone signaling and pathways in perennial trees like cashew is scarce. Therefore, the potential exists to identify hormone regulated mutants or transgenics with improved productivity in perennial fruit crops like cashew.

Plant growth hormones affect nut yield and nutritional qualities. The seed and nutritional qualities also constitute important traits that need consideration. Whereas, there is evidence of positive health benefits by cashew nut and its value added products, the impact of endogenous plant growth hormones on nutritional qualities of nuts and cashew apple has to be determined. Preliminary studies indicate influence of growth hormones on nutritional qualities of cashew apple and its value added products, yet detailed comprehensive studies on improving quality of cashew apple, cashew nut and various value added products through hormonal manipulation is highly desirable for future agro-biotechnological and nutraceutial application.

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