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Manoj Kumar Sahu
Department of Fruit Science and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

GL Sharma
Department of Fruit Science and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

Prabhakar Singh
Department of Fruit Science and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

Hamant Kumar Panigrahi
Department of Fruit Science and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

Tapas Chowdhury
Agricultural Microbiology and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

RR Saxena
Agricultural Statistics and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

Corresponding Author:
Manoj Kumar Sahu
Department of Fruit Science and Social Science, Collage of Agriculture, IGKV, Raipur, Chhattisgarh, India

Effect of plant growth regulators on growth, yield and quality characters of papaya under net house: A review

Manoj Kumar Sahu, GL Sharma, Prabhakar Singh, Hamant Kumar Panigrahi, Tapas Chowdhury and RR Saxena

Abstract
Papaya is a very useful versatile fruit crop grown in India for its delicious fruit, green mannuring as well as nutritional purpose in various regions of India. Papaya is an evergreen plant having hollow, softwood stem and generally unbranched. The leaves are palm like with very long petiole. Naturally growing plants are erect and fruits are of various shapes like round or spherical to oblong produced from the axils of the leaves. Inside the fruit central cavity is having large number of seeds, remain attach with placenta. Sometimes, seeds are absent in the fruit. It was introduced in India in 16th century from Malacca (Kumar and Abrahm, 1943). It has become a popular fruit due to its fast growth, high yield, long fruiting period and high nutrient value as well. In addition, it has been used as vegetable, fruit processing and papain production at immature stage. It became a highly profitable crop now. It is easy to grow and rich in nutrient content. It is highly valued for its digestive properties. The nutritive and medicinal properties of papaya are well known. In recent years, attention has been mainly given to use of growth regulators in modification of growth, flowering, fruiting, fruit quality and yield of different fruit crops. The effect of growth regulators in papaya on number of fruit, fruit yield, fruit weight, fruit diameter, seedling vigour, flowering and fruit setting, sex expression and quality parameters *i.e.* total soluble solids, ascorbic acid, acidity and sugar content have been studied by several workers. The different plant growth regulators like Naphthalene acetic acid (NAA), Gibberellic acid (GA3) and 2, 3, 5-Triiodobenzoic acid (TIBA) have been found important to alter the growth, yield and quality parameters of papaya fruit. Naphthalene acetic acid is an auxin, which is very effective in controlling and directing a number of plant metabolic processes. Foliar sprays of NAA have been found to control pre-mature drop of fruits and increasing size of fruits in papaya. Gibberellic acid plays an important role in increasing the fruit set, fruit weight, length, girth, carotenoid and protein content, while decrease the pectin content in papaya fruit. Among the various anti auxins 2, 3, 5-Triiodobenzoic acid is physiologically the most active. TIBA helps to enhance femaleness in papaya, reduce plant height, and increase in plant girth and spread of plant. TIBA is also found to be best particularly for earliness to first flowering in papaya. In essence, PGR leads to the identification of superior PGR which may be recommended as cultivar and identification of verity with desirable traits for selection as higher yielding verity for improvement programmes.

Keywords: Plant growth regulators (PGR), quality characters and papaya

Introduction
Papaya is botanically known as *Carica papaya* L. and belongs to the family Caricaceae having 48 known species and among them, *Carica papaya* L. is only species grown for edible fruits (Chadha, 1992) [17]. There are wide diversity of biological types of cultivated papaya, which may be dioecious, monoecious and hermaphrodite (Arrilia *et al.*, 1980) [6]. Male plants do not bear any fruit. Normally, the fruit shape from female plant is shorter, but the fruit shape from hermaphroditic plant is longer. The cultivated papaya might have originated as a cross between two species of the genus *Carica* native to Mexico; it is closely related to *Carica pelata*, which occurs in this area and may have arisen, by hybridization (Ram, 1996) [64]. Papaya is an evergreen plant having hollow, softwood stem and generally unbranched. The leaves are palm like with very long petiole. Naturally growing plants are erect and fruits are of various shapes like round or spherical to oblong produced from the axils of the leaves. Inside the fruit central cavity is having large number of seeds, remain attach with placenta. Sometimes, seeds are absent in the fruit.

The papaya is one of the important delicious fruit crops grown in the tropical and sub-tropical parts of the world. It is originated in tropical America and spread to almost all the corners of the tropical world (Hofmeyr, 1938) [33]. It was introduced in India in 16th century from Malacca (Kumar and Abrahm, 1943) [44].

It has become a popular fruit due to its fast growth, high yield, long fruiting period and high nutrient value as well. In addition, it has been used as vegetable, fruit processing and papain production at immature stage. It became a highly profitable crop now. It is easy to grow and rich in nutrient content. It is highly valued for its digestive properties. The nutritive and medicinal properties of papaya are well known. 100gm edible portion of papaya contains moisture 89.6%, carbohydrate 9.5%, proteins 0.5%, fat 0.1%, calorific value 4.0%, minerals 0.4%, calcium 0.01%, phosphorus 0.01%, iron 0.4 mg, carotene (Vit A) 2020 IU, thiamine (Vit B) 40 IU, riboflavin (Vit B2) 250 IU, nicotinic acid 0.2 IU (Ram, 2007). It is generally used in preparation of drugs in pharmaceutical industries and manufacturing of various industrial products (Purseglove, 1968) [62]. The mature fruits of papaya are green to dark green in colour and changed to yellow orange on ripening or red depending on cultivars. Immature fruits of papaya are the rich source of papain and proteolytic enzymes, which are helpful in digestion of protein and used as meat tenderizer (Ram, 1996) [64]. Mature fruits are being utilized in the preparation of candy or tutti-frutti and ripe fruits are also used in the preparation of ready to serve, jam, fruit bar, ice-cream, soft drinks, flavouring crystallized fruit, syrup etc. Presently, the papaya is one of the most important fruit crops of Hawaii, Malaysia, Burma, Sri Lanka, India, Queens Land, South Africa, and other tropical and sub-tropical countries of the world.

In India, it is successfully grown all over the country and is available round the year. Papaya occupies 2.14 per cent total fruit crop area and 6.40 per cent of total fruit production in India. It occupies a cultivated area of 133 thousand hectares with 5699 thousand MT of production with average productivity of 42.3 t/ha (Anon., 2015 a). The important papaya growing States are Andhra Pradesh, Gujarat, Maharashtra, Karnataka, Madhya Pradesh, Chhattisgarh, West Bengal, Telangana, Tamil Nadu, Assam, Karla, Uttar Pradesh and Rajasthan have ideal climate conditions for its growth and production. Chhattisgarh is one of the State in which papaya is being grown in an area of 13623 ha with annual production of 305523 metric tones with the productivity of 23.3 t/ha, accounting 11.6 and 6.85 per cent area and production, respectively (Anon., 2015 b).

Climate of Chhattisgarh is well-suited for cultivation of papaya therefore; it is being grown almost in all districts of Chhattisgarh. Although, production of papaya in the country as well as State is very high but export quality production is very low. There are number of constraints for export quality production of papaya such as lack of exportable varieties, lack of consistency and supply, large tracts of low and unproductive plantation, poor crop management, lack of knowledge about plant growth regulators and their suitable concentrations, heavy post-harvest losses and all these factors also results for high cost of production. The use of plant growth regulators has assumed an integral part of modern fruit production to improve the quality and production of fruits and it has resulted in outstanding achievements in a number of fruit crops with regard to improvements in yield and quality (Jain and Dashora, 2011) [36]. Because of its diverse effect, it is possible to use certain growth regulating chemicals at particular stage of fruit growth and development to exhibit maximum effect. In recent years, attention has been mainly given to use of growth regulators in modification of growth, flowering, fruiting, fruit quality and yield of different fruit crops.

The effect of growth regulators in papaya on number of fruit, fruit yield, fruit weight, fruit diameter, seedling vigour, flowering and fruit setting, sex expression and quality parameters *i.e.* total soluble solids, ascorbic acid, acidity and sugar content have been studied by several workers. The different plant growth regulators like Naphthalene acetic acid (NAA), Gibberellic acid (GA3) and 2, 3, 5-Triiodobenzoic acid (TIBA) have been found important to alter the growth, yield and quality parameters of papaya fruit. Naphthalene acetic acid is an auxin, which is very effective in controlling and directing a number of plant metabolic processes. Foliar sprays of NAA have been found to control pre-mature drop of fruits and increasing size of fruits in papaya. Gibberellic acid plays an important role in increasing the fruit set, fruit weight, length, girth, carotenoid and protein content, while decrease the pectin content in papaya fruit.

Among the various anti auxins 2, 3, 5-Triiodobenzoic acid is physiologically the most active. TIBA helps to enhance femaleness in papaya, reduce plant height, and increase in plant girth and spread of plant. TIBA is also found to be best particularly for earliness to first flowering in papaya. The research work on plant growth regulators in papaya is still meagre especially in Chhattisgarh; therefore it needs to be worked out the efficiency of plant growth regulators on papaya in respect to growth, yield and qualitative parameters. Red Lady is an important and dominant cultivar of papaya, which is performing very well in the climate of Chhattisgarh.

Papaya is one of the important table fruit as well as commercial crop because of its high nutritive and medicinal value, gives one of the highest productions per hectare area and income next to banana. Plant growth regulators have remained an important component in fruit crop from time immemorial because they were effective means of quantitative as well as qualitative improvement in growth and development of crops. Plant growth and development as well as the responses to environmental factors, are highly regulated by complex and co-ordinated action of the endogenous hormones. In addition to this other plant growth regulators are also reported to be very helpful in this direction by altering the growth and development of plant. The fruiting is regulated at different times of flower emergence and at different intensities to maintain the productivity of the papaya plants (Sharma and Singh, 2000) [69]. The different timings of crop regulation with different chemicals have produced different effects on fruit yield and quality. They have the potential of increasing plant productivity and quality through influence on various metabolic processes. Plant growth regulators are known to improve fruit size, appearance and aril quality by direct effect on fruit growth and development or indirectly by regulating crops load and tree vigour. The exogenous application of growth regulators has been found very effective in improving fruit size and quality of fruit crops.

Few literatures are available on plant growth regulators in papaya; however attempts are made to collect related on the aforesaid aspects. The works on effect of plant growth regulators on papaya and other fruit crops have been summarized under following heads:

1. Effect of plant growth regulators on growth, flowering and fruiting characters.
2. Effect of plant growth regulators on yield and yield attributing characters.
3. Effect of plant growth regulators on quality parameters.

4. Effect of plant growth regulators on Benefit: Cost ratio.

1. Effect of plant growth regulators on growth, flowering and fruiting characters

Cobianchi (1972) [20] noted that the SADH reduced the length and number of the internodes. TIBA was less effective and reduced the number of internodes in apple. Guha and Chaturvedi (1972) [20] observed that plant height was enhanced by GA3 treatments; this effect was associated with greater internode lengths and became more marked as GA3 concentration increased in papaya. Pramanik and Bose (1974) [60] studied different fruit plants, where the flowers were sprayed once with 2, 4-D at 5, 10 or 50 ppm or with GA3, NOA or 2, 4, 5-T at 10, 50 or 100 ppm respectively. The effect of the treatments on fruit set and retention varied considerably between species. However, GA3 improved fruit set in all. Kumar and Prasad (1997) [43] studied the effect of different growth regulators, among various treatments, 50 ppm GA3 was the most effective in increasing the number of female flowers (94.24) and percentage fruit set (53.06%) in papaya. Subhadrabandhu *et al.* (1997) [78] found that GA3 treated seedlings grew more vigorously than control plants. Over the 90 days of growing period, maximum growth rate was recorded in all treatments. Plants treated with NAA flowered about 6 days earlier than those in the control treatment, while plants treated with GA3 flowered about 20 days earlier than those in the control in papaya. Bhattacharyya and Rao (1981) [12] reported that the ripening was shortest (141 days) in fruit treated with TIBA at 100 ppm while untreated control fruit took 153 days to ripen. Singh and Rajput (1986) [72] noted that maximum shoot growth with 2% calcium nitrate + 40 ppm GA3 However, the best overall results with regard to shoot growth, early flowering and maximum reduction in the flowering period were obtained with 2% calcium nitrate + 100 ppm NAA. Biswas *et al.* (1988) noted that the application of NAA tended to increase the number of leaves produced per plant in papaya. Hore *et al.* (1989) [34] recorded the maximum and minimum plant heights were (202.52 and 112.50 cm) attained with GA3 at 200 ppm and GA3 at 100 ppm, respectively. They also observed that plant girth and spread were also significantly influenced with application of GA3 200 ppm in papaya. Ghanta and Mitra (1998) [27] studied the effect of different plant growth regulators *i.e.* GA3 (25 ppm and 50 ppm), NAA (50, and 100 ppm), TIBA (25 ppm and 50 ppm), Ethrel (300 ppm and 500 ppm) and MH (200 ppm and 500 ppm) sprayed at 45 days after transplanting and observed that plant height and internodal length of papaya were increased by NAA, GA3 and ethrel, while decreased by MH and TIBA. All chemicals increased the girth and number of leaves per plant. Flowering was hastened by 10 to 25 days by the chemicals. Morales *et al.* (1999) [52] reported that GA3 30 ppm concentration showed positive increase in height of plant, number of leaves, shoot girth and length of the internodes in papaya as compared to 10 and 20 ppm GA3. They further advocated that growth of papaya was increased in the tune of shoot height, leaf area and shoot dry weight with the use of 30 ppm GA3. Mir *et al.* (2004) [51] recorded that the application of NAA at 10, 15, 20, 25, 30 and 35 ppm, significantly increased plant height, plant spread, number of leaves per plant, petiole length, leaf area index, days to first flowering and days to fruit bud development in strawberry. Agrawal and Dikshit (2008) [2] recorded that NAA 100 ppm applied at flowering stage significantly increased the shoot length, number of leaves and leaf area followed by GA3 50 ppm and control in sapota. Pusdekar and Pusdekar (2009) [62] conducted an experiment on plant growth regulators in papaya and concluded that ethrel, Cycocel and MH induces early flowering in papaya cv. Co-2. Syamal *et al.* (2010) [80] reported that plant girth, plant spread and the reduction of number of days taken for fruit bud differentiation, were greatly influenced by application of 2, 3, 5-Triiodobenzoic acid (TIBA) at the concentration of 100 ppm followed by 150 ppm in papaya. Singh *et al.* (2011 a) [75] noted that the application of TIBA at 150 ppm showed highest plant girth and plant spread as compared to control treatments. Singh *et al.* (2011 b) [76] reported that among different chemicals, NAA 10 ppm was found significantly effective in enhancing the growth of new shoot (29.66 sq./m), number of leaves (32.66) and number of flower per shoot (1,490) over control in mango. They further observed that fruit set was maximum in tree sprayed with NAA 10 ppm followed by NAA 15 ppm and 2, 4-D at 15 ppm. Prasad *et al.* (2012) [61] revealed that the different mulching with application of plant growth regulators, significantly affects the plant growth of strawberry fruit. Application of GA3 100 ppm + black polythene mulch recorded maximum plant height (23.26 cm), East- West plant spread (32.02 cm), North South spread (32.08 cm), maximum number of flowers (38.21/plant), minimum days to first flowering (62.88 days), First fruit set (4.10 days), early maturity of fruits (19.05 days) and early harvesting (81.61 days). Kukali *et al.* (2014) [42] conducted a trial on different concentration of GA3 at 75, 100 and 125 ppm in grapes and they confirmed that all treatments showed an acceleration of the flowering and maturation process as compared to control. Further they concluded that application of GA3 at 125 ppm concentration induced ripening of grapes about 10 days earlier as compared to untreated plants. Hazarika *et al.* (2016) [33] conducted a trial on effect of plant growth regulators on growth characters of papaya and concluded that the treatment GA3 200 ppm showed maximum value with respect to different growth parameters *viz*., plant height, plant girth and plant spread.

2 Effect of plant growth regulators on yield and yield attributing characters

Asi and Ali (1970) [8] reported that NAA at the higher dose in Kinnow mandarin caused significant increases in fruit weight and juice content, while reductions in peel and rag percentages. Shanmugavelu *et al.* (1973) [68] advocated that 200 ppm GA3 and 50 ppm TIBA increased fruit size and enhanced the fruit yield (t/ha) in papaya. Further, they have reported that GA3 50 ppm recorded maximum weight, size and volume of papaya fruit. Kumar and Hoda (1974) [44] found that application of GA3 at 200 ppm concentration applied twice at 7 days interval during flowering stage in guava increased fruit set and fruit size. They further concluded that fruit retention percentage was greatly influenced with 200 ppm concentration of GA3. Das and Mahapatra (1975) [22] observed that final fruit retention of sapota was found highest in plant treated with Planofix at 300 ppm. Similarly the maximum fruit size was also recorded under the same treatment. Bhattacharyya and Rao (1981) [12] concluded that application of CCC (chlormequat) at 1000-5000 ppm, ethrel (ethephon) at 100-300 ppm or TIBA at 50-200 ppm, applied at flowering stage in papaya increased the

pulp: rind ratio as compared to control. Masalkar and Wavhal (1991) [50] reported that the maximum fruit weight, fruit volume and pulp weight of beer with the application of gibberellic acid (GA3). Chattopadhyay and Jana (1985) [18] noted that the application of NAA at 100 ppm concentration gave the highest yield of 42.7 t/ha as compared to control (36.2 t/ha) in banana cv. Giant Governor. Hore *et al.* (1989) [34] recorded that the largest size fruits with MH at 250 ppm, while the maximum fruit weight (1.69 kg) and yield (68.71 kg/plant) was registered under application of GA3 at 100 ppm in papaya. Ding *et al.* (1991) [24] studied the effects of B, Ca, Mn and the growth regulators NAA, GA3 and IAA in loquat and they recorded that fruit set was increased by 63.5-82.4% with 10-50 ppm GA3. Further they advocated that application of NAA and IAA at 50 ppm concentration also increased fruit set. Chaudhary *et al.* (1994) [19] observed that GA3 at 40 ppm concentration recorded greatest fruit weight (25.43 g), volume (26.32 cc), pulp weight (22.87 g/fruit), pulp: seed ratio (8.93:1) and percentage fruit retention (89.51%), as compared to control 18.74 g, 19.40 cc, 15.81 g, 5.40:1 and 69.20%, respectively in loquat fruit cv. Thamos Pride. Kumar and Prasad (1997) [43] studied the effect of different plant growth regulators and concluded that among various treatments, 50 ppm GA3 was the most effective in increasing the fruit size (20.65 cm × 17.57 cm), fruit weight (1.725 kg), volume (1850 cc), flesh thickness (3.70 cm) and fruit yield (540.25 q/ha) in papaya. Vijayalalitha and Rajasekaran (1997) [82] noted that NAA application considerably increased fruit length and circumference compared with the control. Fruit size increased as NAA concentration increased up to 100 ppm in sapota cv. Oval. Dai *et al.* (1998) [21] reported that the application GA3 were the best for increasing fruit set, fruit weight and yield, compared with the control in litchi fruit. Ghanta and Mitra (1998) [27] studied the effect of different plant growth regulators *i.e.* GA3 (25 ppm and 50 ppm), NAA (50, and 100 ppm), TIBA (25 ppm and 50 ppm), Ethrel (300 ppm and 500 ppm) and MH (200 ppm and 500 ppm) sprayed at 45 days after transplanting and observed that all the plant growth regulators at different concentrations produced marked increase in number of fruit, fruit yield, fruit weight, fruit size, pulp and seed ratio. The highest fruit yield 45.63 kg/plant and 114.07 t/ha were recorded under the treatment 25 ppm GA3 as compared to control (28.2 kg/plant and 76.6 t/ha, respectively) in papaya. Vishwakarma *et al.* (2000) [83] noticed that GA3 50 ppm concentration showed significant effect on the fruit length, fruits size, fruit diameter, pulp: peel ratio, fruit weight and yield of papaya fruit as compared to 2,4-D (10, 25, 50 ppm) and control. Arzani and Akhlaghi-Amiri (2001) [7] observed that application of 2, 4-D and NAA at 300 and 400 ppm concentration, significantly increased fruit weight compared with the untreated control. Both growth regulators increased juice content and the marketability of Satsuma mandarin. Further they concluded that the best result and appearance of fruit was observed under 400 ppm concentration of NAA. Mir *et al.* (2004) [51] reported that the physical parameters *i.e.* length, diameter and specific gravity of strawberry cv. Sweet Charley increased with increasing levels of Naphthalene acetic acid. Kher *et al.* (2005) [40] concluded that foliar application of plant growth regulators had favorable effect on the physical characters of guava fruits like fruit weight, specific gravity and firmness. They also found that spraying of GA3 at 90 ppm concentration sprayed at 30 days before harvest was identified as the most effective treatment. Nicolaescu *et al.* (2009) [54] observed that the application of GA3 increased bunch weight and berry weight, while decreased the cluster structure rate in Cardinal variety of grape. Further they advocated that application of GA3 at 50 ppm concentration increased yield up to 31.4-85.8% and found optimum concentration for most of the physical parameters of the grape. Pusdekar and Pusdekar (2009) [62] conducted an experiment on effect of plant growth regulators in papaya and concluded that NAA was found to be most effective amongst the plant growth regulators in respect to fruit weight, fruit volume and cavity width of fruit. Abu-Zahra (2010) [1] reported that the application of GA3 at 30 ppm concentration improved the berry shattering, heavier berries, hastened berry diameter, and produced larger berries in comparison to the control trees. In addition, bunch weight and length were also increased under the same treatment. Syamal *et al.* (2010) [80] reported that application of GA3 at 100 and 150 ppm concentration recorded maximum plant height and physical parameters of fruit *i.e.* length, diameter and weight of papaya fruit as compared to untreated plants. Singh *et al.* (2011 a) [75] conducted a field trial on effect of different plant growth regulators on papaya. Foliar spray of NAA 100 ppm & 150 ppm and GA3 200 ppm were provided to the papaya plant and they reported that yield and yield attributing characters were found maximum under NAA 100 ppm over control. Singh *et al.* (2011 b) [76] observed that the application of NAA at 10 ppm concentration significantly increased the fruit size, fruit weight (201.66 g), pulp content (77.15%) and yield (102.33 kg) of mango as compared to control plants. Nkansah *et al.* (2012) [55] observed that the NAA and GA3 treated plants, significantly increased fruit retention and tree yield. They also noted that GA3 (25 ppm) and NAA (25 ppm) gave the best results in terms of increasing fruit set, fruit retention, number of fruits per cluster and per plant, fruit weight and yield. Significant differences were also observed between the quality parameters of fruits harvested from treated and control trees. Further they finally concluded that GA3 at 25 ppm and NAA at 25 ppm concentration can be employed for spraying in mango at full bloom stage to increase fruit set, fruit retention and yield of plant. Gill and Bal (2013) [28] concluded that the highest fruit yield was recorded in trees sprayed with 30 ppm GA3, while higher fruit size and weight were noted under 20 and 40 ppm GA3 and 30 ppm NAA in beer. Goswami *et al.* (2013) [29] concluded that application of NAA at 50 ppm was found effective in increasing number of fruits per tree, fruit weight, yield and number of hermaphrodite flower in pomegranate cv. Sinduri. The minimum fruit drop per cent was also noted under the same treatment. Lal *et al.* (2013) [45] reported that the application of 50 ppm GA3 registered maximum fruit length (9.8 cm), fruit girth (10.23 cm), fruit weight (182 g), fruit volume (178.3 cc), minimum fruit drop per cent (38.8) and yield (37.1 kg/plant) in guava. Arora and Singh (2014) [5] revealed that application of NAA at 30 ppm applied to ber caused significant increase in fruit size, fruit length, breadth, weight and volume of fruit. Bhogave *et al.* (2014) [13] studied on foliar application of gibberellic acid (150 and 200 ppm) and 2, 3, 5-Triiodobenzoic acid (TIBA) (150 and 200 ppm) on papaya and resulted maximum fruit length, number of fruits per plant, flesh thickness associated with low fruit cavity, less number of seeds per fruit and yield spraying of 150 and 200 ppm 2, 3, 5-Triiodobenzoic acid (TIBA). Pereira *et al.* (2014) [58] observed that application of GA3 increased the percentage

of fruit set, fruit weight, pulp weight, peel weight and pH of fruit with increasing concentration of GA3 in atemoya. Anawal *et al.* (2015) [3] observed that application of NAA at 40 ppm concentration was found effective in increasing number of fruits per tree (62.44), fruit length (8.66 cm), fruit diameter (8.71 cm), fruit weight (262.23 g) and fruit volume (255.44 ml) in pomegranate cv. Bhagwa. Khajehyar *et al.* (2015) [39] concluded that application of GA3 at 50 or 100 ppm sprayed at mid-May, effectively impacted on several quality attributes, including fruit weight, length and diameter of apricot. Hazarika *et al.* (2016) [33] conducted a trial on effect of plant growth regulators on yield and yield attributing characters of papaya and concluded that the treatment GA3 at 200 ppm concentration showed maximum value with respect to different growth parameters *viz*., number of fruits per plant, fruit length, fruit diameter, fruit circumference, fruit weight & fruit volume in Red Lady cultivar of papaya.

3 Effect of plant growth regulators on quality parameters

Asi and Ali (1970) [8] reported that NAA at the higher concentration caused significant increase in total sugars and reducing sugar. They further concluded that application of NAA significantly influenced the quality attributing parameters in Kinnow mandarin. Shanmugavelu *et al.* (1973) [68] conducted a trial on effect of plant growth regulators on fruit quality parameters of papaya and they concluded that total sugar, reducing sugar and non- reducing sugar, TSS and carotene content of fruits were influenced significantly at 50 ppm concentration of GA3 as compared to control. Kumar and Hoda (1974) [44] observed that GA3 at 100 or 200 ppm concentration applied at 7 days interval in guava fruit enhanced fruit quality and reduce the acidity percentage. Similarly the quality parameters *i.e*. total sugar, reducing sugar, vitamin 'C' and total soluble solids were also found maximum under the same treatment. Bagde and Kandalkar (1981) [9] observed that fruit quality of Sardar guava was best improved by application of GA3 at 75 or 100 ppm or NAA at 60 or 80 ppm concentration. Bhattacharyya and Rao (1981) [12] concluded that application of CCC (chlormequat) at 1000-5000 ppm, ethrel (ethephon) at 100-300 ppm and TIBA at 50-200 ppm applied at flowering stage of papaya, significantly increased total sugar content of papaya fruit, however the highest total sugar (9.23) was recorded under the plants treated with TIBA at 100 ppm concentration. Masalkar and Wavhal (1991) [50] stated that foliar application of GA3 increased non-reducing sugar, ascorbic acid contents and lowest percentage of stone in Umran variety of ber. El-Hammady *et al.* (1990) [26] reported that application of GA3 applied at 100 ppm concentration produced the highest yield in the 2 successive seasons in Balady cultivar of mandarin. Southwick and Yeager (1993) [77] concluded that the GA3 (50 ppm) sprayed at 21 days before harvest, did not reduce yield but increased fruit weight and other physico-chemical composition of apricot fruit. Chaudhary *et al.* (1994) [19] observed that NAA at 40 ppm resulted the highest TSS (12.90%), reducing sugars (7.58%), non-reducing sugars (1.36%) and ascorbic acid content (4.10 mg/100 g) and the lowest titratable acidity (0.924%) content in loquat fruit. Kumar and Prasad (1997) [43] observed that the application of GA3 at 50 ppm concentration recorded maximum total soluble solid content (10.5%), total sugars (8.74%), reducing sugar (7.15%), non-reducing sugar (1.59%), vitamin 'A' (2450 I.U. /100 g) and vitamin 'C' (ascorbic acid) content (58.50 mg/100 g) in papaya. Ghanta and Mitra (1998) [27] studied the application of 50 ppm GA3 registered the maximum total soluble solids, ascorbic acid and sugar: acid ratio and the maximum carotene content were recorded under 200 ppm ethrel in papaya pulp. Barman and Das (2002) [10] noted that the titratable acidity percentage and sugar: acid ratio was better with application of GA3 at 200 ppm concentration in Barjahaji cultivar of banana. Mir *et al.* (2004) [51] reported that the quality parameters *i.e.* total soluble solids, total sugar, acidity, pH value and vitamin 'C' content increases with the increasing levels of NAA in strawberry cv. Sweet Charley. Kher *et al.* (2005) [40] concluded that foliar application of plant growth regulators had favorable effect on the physico-chemical characters of guava fruits like total soluble solids (TSS), total sugars, reducing sugars, acidity, TSS: acid ratio and ascorbic acid content at harvest. They further stated that GA3 at 90 ppm concentration sprayed at 30 days before harvest was identified as the most effective treatment. Pusdekar and Pusdekar (2009) [62] reported that application of NAA was found to be most effective amongst the plant growth regulators regarding the TSS of papaya fruit cv. Co-2. Abu-Zahra (2010) [1] observed that GA3 application influenced the total soluble solids and titratable acidity. Further they concluded that GA3 is an effective plant growth regulators for improving berries of grapevine cv. Thompson seedless as compared with girdle treated bunches. Syamal *et al.* (2010) [80] reported that number of fruit per plant and yield per plant in papaya were greatly influenced by application of 2, 3, 5-Triiodobenzoic acid (TIBA) at the concentration of 100 and 150 ppm. Sarkar and Ghosh (2011) studied the effect of different growth regulators (*i.e.* 2, 4-D, NAA, GA3 and Planofix) on the bio-chemical composition of mango cv. Amrapali and concluded that GA3 at 20 ppm gave the highest total soluble solids (21.22%), total sugar content (16.77%) and reducing sugar (7.0%), while the highest acidity (0.26%) was recorded under 30 ppm NAA in mango. Singh *et al.* (2011 a) [75] reported that the TSS: acid ratio was significantly higher with application of NAA at 10 ppm concentration, while the highest ascorbic acid content (31.65 mg) was recorded under NAA at 15 ppm followed by 2, 4-D at 15 ppm. Gill and Bal (2013) [28] reported that the tree sprayed with 50 ppm NAA and 30 ppm GA3 obtained higher content of total soluble solids, while acidity content of Indian Jujube was recorded minimum under the same treatments. Kukali *et al.* (2014) [42] concluded that the application of gibberellic acid influenced commercial appearance and performance of grape. Sugar content of fruit was significantly increased (0.6-4.2%) with the application of GA3 as compared to control. Bhogave *et al.* (2015) [14] concluded that gibberellic acid increased the total sugars, reducing sugars content and sugar: acid ratio in papaya, whereas minimum values of these characters associated with control treatment. In addition, reduction in acidity was recorded in GA3 treated plants, while it was highest in control. However, TSS and non-reducing sugars were recorded maximum in the plants treated with TIBA. They further stated that NAA treated plants were also found effective in improving TSS, total sugar, reducing sugars and reducing acidity of papaya fruit. Anawal *et al.* (2015) [3] observed that application of NAA at 40 ppm was found effective in increasing TSS (16.76%), total sugars (15.58%), reducing sugars (13.83%) and non-reducing sugars (1.75%) against control in pomegranate cv. Bhagwa.

4 Effect of plant growth regulators on Benefit: Cost ratio

Prasad *et al.* (2012) reported that different mulching with plant growth regulators significantly affects the plant growth and yield of strawberry fruit. They further concluded that application of GA3 100 ppm along with black polythene mulch increased the Benefit: Cost ratio (1:1.62) as compared with control plants of strawberry. Khopade *et al.* (2015) [41] conducted an experiment on yield and economics of sapota trees, which revealed that application of 75% RDF + Bio-fertilizers (*Azospirillum* + PSB) @40 ml/tree + GA3 @ 50 ppm + micronutrient mixture Grade 4 @ 0.5% registered significantly highest Benefit: Cost ratio 1: 4.45 in sapota cv. Kalipatti. Rajput *et al.* (2015) [63] revealed that application of 0.2% boron + NAA 150 ppm gave higher 1:6.6 Benefit: Cost ratio in 1: 6.6 guava cv. Lucknow - 49. Digrase *et al.* (2016) [23] conducted a trial on pomegranate and recorded that application of GA3 75 ppm + boron 0.3 per cent gave highest gross monetary return (6,96,820 Rs/ha), net monetary returns (4,90,740 Rs/ha) and Benefit: Cost ratio (2.86). Jawed *et al.* (2017) conducted a field experiment on guava cv. G.27 and conducted that application of 0.40% zinc sulphate + 30 ppm gibberellic acid showed significantly higher net returns (1,18,663.33 Rs/ha) as well as Benefit: Cost ratio 1: 3.85 over the other treatments.

Conclusion

Climate of Chhattisgarh is well-suited for cultivation of papaya therefore; it is being grown almost in all districts of Chhattisgarh. Although, production of papaya in the country as well as State is very high but export quality production is very low. There are number of constraints for export quality production of papaya such as lack of exportable varieties, lack of consistency and supply, large tracts of low and unproductive plantation, poor crop management, lack of knowledge about plant growth regulators and their suitable concentrations, heavy post-harvest losses and all these factors also results for high cost of production. The different plant growth regulators like Naphthalene acetic acid (NAA), Gibberellic acid (GA3) and 2, 3, 5-Triiodobenzoic acid (TIBA) have been found important to alter the growth, yield and quality parameters of papaya fruit. Naphthalene acetic acid is an auxin, which is very effective in controlling and directing a number of plant metabolic processes. Foliar sprays of NAA have been found to control pre-mature drop of fruits and increasing size of fruits in papaya. Gibberellic acid plays an important role in increasing the fruit set, fruit weight, length, girth, carotenoid and protein content, while decrease the pectin content in papaya fruit. Among the various anti auxins 2, 3, 5-Triiodobenzoic acid is physiologically the most active. TIBA helps to enhance femaleness in papaya, reduce plant height, and increase in plant girth and spread of plant. TIBA is also found to be best particularly for earliness to first flowering in papaya. The research work on plant growth regulators in papaya is still meager especially in Chhattisgarh; therefore it needs to be worked out the efficiency of plant growth regulators on papaya in respect to growth, yield and qualitative parameters. Red Lady is an important and dominant cultivar of papaya, which is performing very well in the climate of Chhattisgarh. The different timings of crop regulation with different chemicals have produced different effects on fruit yield and quality. They have the potential of increasing plant productivity and quality through influence on various metabolic processes. Plant growth regulators are known to improve fruit size, appearance and aril quality by direct effect on fruit growth and development or indirectly by regulating crops load and tree vigour. The exogenous application of growth regulators has been found very effective in improving fruit size and quality of fruit crops.

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