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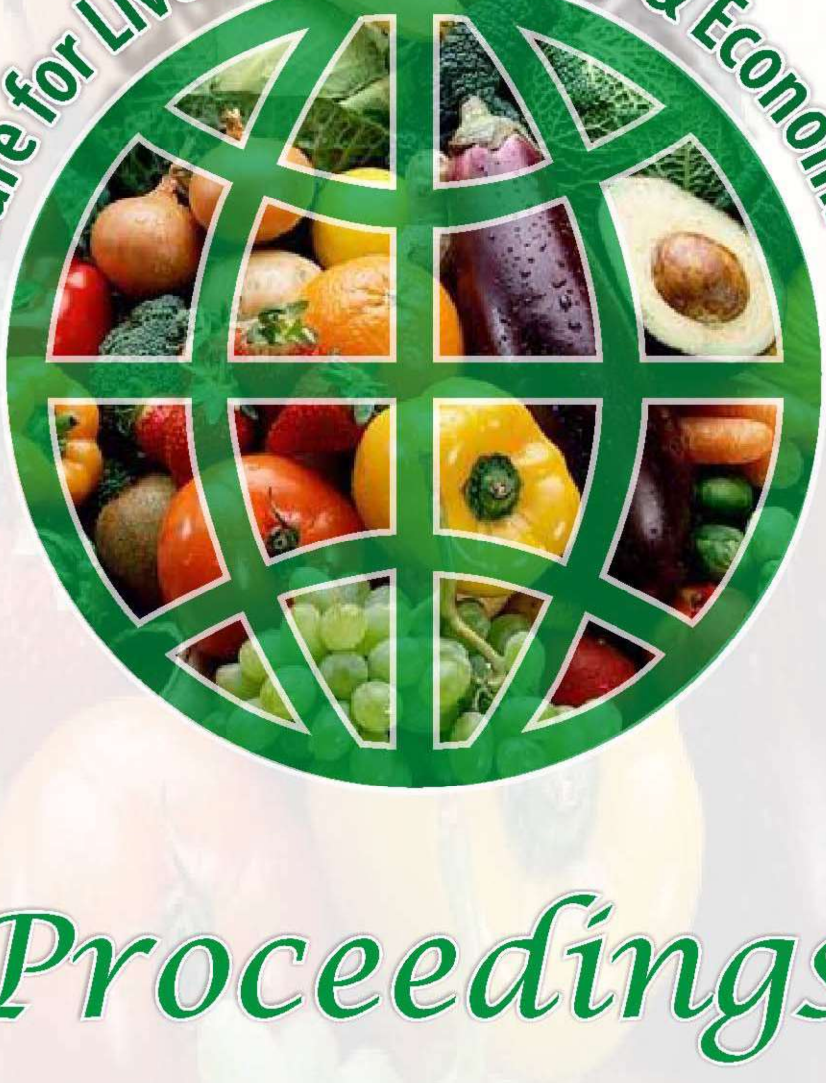

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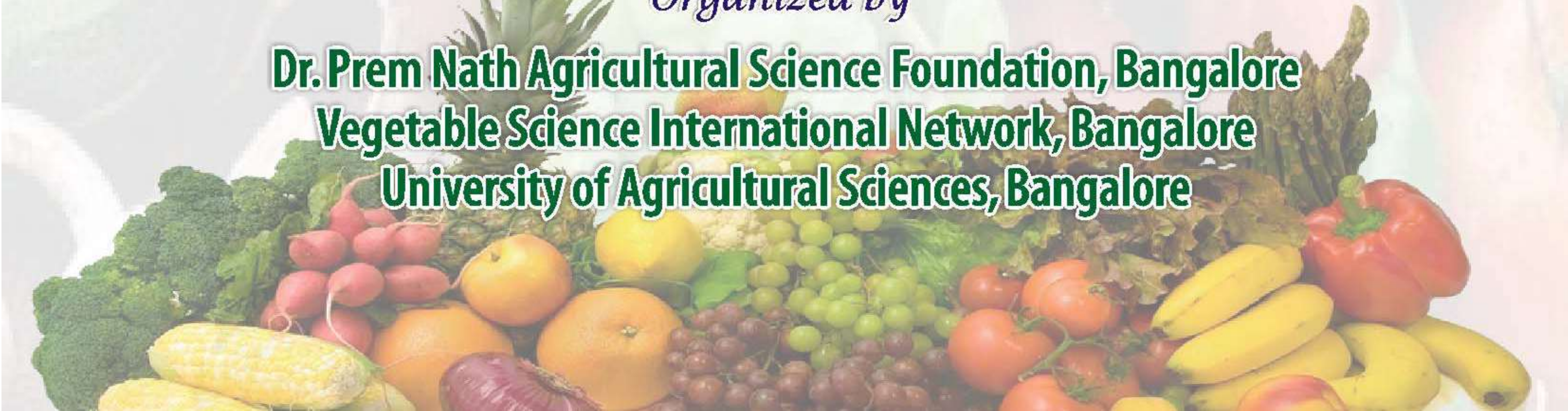

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# PLANT BIOREGULATORS IN SUSTAINABLE FRUIT PRODUCTION

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## INTRODUCTION

Plant bioregulators (PBRs) play important roles in modern agriculture and horticulture, however, they account for nearly 5% of the total sales of crop protection agents. Many plant bioregulators known by the term phytohormones / plant hormones are naturally present in the plant system and play important role in growth and development of plants. For sustainable fruit production to overcome the deficiencies of endogenous plant bioregulators, exogenous application of plant bioregulators is necessary. There are at present five groups of plant bioregulators viz. auxins, gibberellins, cytokinins, ethylene and abscissic acid. Besides, some other distinct groups, the steroids, brassinosteroids, jasmonic acid, oligosaccharides and fusicoccin have also been discovered from plants and are used intensively in agriculture / horticulture.

Besides, naturally occurring plant bioregulators other chemicals exhibiting growth regulatory activities have wide applications in horticulture. Among the important ones are chloromequat chloride (cycocel or CCC), mepiquat chloride, ancymidol, flurprimidol, paclobutrazol (cultar), uniconazol etc. Other prominent ones are synthetic auxins viz. indole butyric acid (IBA), á-naphthalene acetic acid (NAA), phenoxy acetic acid, â-naphthoxyacetic acid (BNOA), 2,4-dichlorophenoxy acetic acid (2,4-D), 4-chloro phenoxy acetic acid (4-CPA), 2, 4, 5-trichlorophenoxyaceticacid (2,4,5-T), 4-{(chloro-o-tolyl)oxy} butyric acid (MCPB) and benzothiazole-2-oxyacetic acid (BOA), synthetic cytokinins, and growth retardants viz. SADH, maleic hydrazide (MH), morphactin, diaminozide (B-9, SADH, alar) etc. A list of such common bioregulators, their chemical and commercial names and functions are given in the Table 1, and the functional similarities and dissimilarities of bioregulators are given in Table 2 and 3.

## USE OF PLANT BIOREGULATORS IN FRUIT CROPS

Propagation, control of vegetative vigour, stimulation of flowering, blossom thinning, regulation of crop load, breaking dormancy and delay or stimulation of fruit maturity and ripening are important examples of processes in fruit crops that can be regulated with exogenous applications of bioregulators (Table 4).

### *1. PROPAGATION*

Use of plant bioregulators is very common in the propagation of fruit crops by conventional and *in vitro* methods.

### a. Vegetative propagation by cuttings, layering and budding/grafting

There are many methods of applying auxins to stem cuttings, among which the quick dip, prolonged soaking and powder methods are widely used. In the quick dip method, a high concentration of auxin dissolved in a volatile solvent like ethyl alcohol is used for a quick treatment of cuttings for few seconds. Several fruit crops are being propagated by this method viz., lemon, grape, apricot, guava, loquat etc. Techniques of stooling and layering have been successful in the crops like apple, mango and guava. Auxins such as NAA, IAA have also been found promising in increasing the graft intake in grapes and avocado by stimulating cambial activity.

**b. Plant tissue culture**

The plant tissue culture or micropropagation has a potential of being the rapid and cheaper method of producing the horticultural plants. The procedure for manipulation through tissue culture techniques rely on mass production of shoots, either adventitiously from explants or by enhanced auxillary branching of excised shoot tips and their rootings. All the successes in micropropagation, cell and protoplast culture, anther culture, ovule culture, embryo culture, somatic embryogenesis etc. in various fruit crops have been accomplished with semi solid or liquid nutrient media supplemented with suitable plant bioregulators.

***2. PLANT GROWTH AND DEVELOPMENT***

Researches have revealed that the process of growth and development in plant is under the regulatory control of endogenous hormones. Thus, alteration in the plant growth and development is possible by manipulating the endogenous levels of hormones through exogenous applications. Various applications of plant bioregulators in plant growth ad development are as follows.

**a. Breaking dormancy**

GA applications are now being made for accelerated seed germination in citrus, cherry, avocado, apple and peach. Pre-sowing soaking of seeds in GA solution was found to stimulate the germination of trifoliate orange, sweet orange, cleopatra mandarin and acid lime. GA was also effective in breaking seed dormancy in scarified seed of ber and annona.

**b. Prolonging dormancy**

Prolongation of dormancy by bioregulators has its own advantage in crops like citrus and grapes. Citrus buds pass through a state of rest during winter when night temperature falls below minimum level for normal growth. Shoot growth during this time of year is often undesirable as it may suffer injury. Growth retardants viz. ABA, SADH and CCC applied to foliage delayed the bud break.

**c. Regulation of vegetative growth**

Various growth retardants have been used to restrict the vegetative growth of the plant. Restriction of vegetative growth is often desirable in order to facilitate better management practices. In fruit crops, tree size control is receiving attention for producing dwarf trees for high density orcharding in the recent past. Commercially adopted growth retardants are AMO 1618, CCC, Ancymidol, Paclobutrazol, B-9 and Chloramquat. Of these, treatments with Paclobutrazol were found effective in reducing the growth of pear, peach, lemon, apple, litchi, apricot, plum and mango. Abscissic Acid, and Dimethipin have been successfully used in the defoliation or leaf thinning of nursery fruit plants.

**d. Flowering**

PBRs have been used successfully as foliar sprays to induce flowering, increase flowering, synchronize bloom, or change the time of flowering to avoid adverse climatic conditions or to shift harvest to a time when the market is more economically favorable. Ethylene @ 200-400 ppm induces flowering in pineapple. In litchi, 500 ppm NAA application was found optimum for improved flowering by mobilization of assimilates in the trees. SADH promoted flowering in apple, pear, peach, lemon and blueberry and reduced shoot growth. Grape and lemon responded to CCC treatments with increased flowering. Paclobutrazol has been effective in initiation and promotion of flowering in mango.

**e. Fruit set**

In fruits like apple, pear, peach, apricot, almond, fig, grape etc. application of gibberellins produces parthenocarpic fruit development. GA treatment was also effective in improving fruit set in blueberry and cranberry. In grapes, 4-CPA application replaced the cultural practice of girdling for improving fruits set. Treatment with 4-CPA was also effective in fig cultivation. It served as an alternative to costly techniques of cross pollination and caprification for improving fruit set. Similarly, the treatments with 2,4,5-T or GA at pink bud stage were promising in improving fruit set in pears by obviating the need for cross pollination. Treatments of GA, 4-CPA or B-NOA proved advantageous in increasing fruit set in strawberry, peach, plum, cherry etc. PBRs sprays are applied to increase fruit size directly by stimulating cell division or to increase fruit size indirectly by decreasing fruit number through the application of PBRs that reduce the number of flowers formed or promote flower or fruit abscission.

**f. Fruit ripening**

The alteration in the period of fruit ripening may be necessary in meeting the early/late market demand, in staggering fruit harvest and to avoid the effects of unfavourable weather. Ethylene is one hormone that exhibits remarkable effects on hastening of fruit ripening. In lemons, dipping in 1000 ppm Ethephon resulted in attainment of marketable yellow colour. Similarly, a large variety of fruits such as banana, mango etc., can be ripened faster with ethylene treatment. Uneven ripening in coloured varieties of grape viz. Beauty Seedless, Gulabi etc. is a major impediment in viticulture. The proportion of green berries at harvest can be reduced considerably by the application of Ethephon @ 250 ppm at colour break stage of the berries.

**g. Fruit thinning**

Thinning of fruits helps in optimizing the fruit size and quality. The traditional practice of hand thinning is cumbersome and labour intensive. The bioregulators employed as the alternative are effective and cheap tools for thinning. Applications of sodium 4, 6-dinitro-o-cresol (DNOC) at full bloom or NAA at post bloom caused satisfactory thinning in apple orchards. Similarly, DNOC sprays are effective in the stone fruits such as apricot, plum, prune, sweet cherry and pear. Pre-bloom application of GA results in optimum fruit set and loose and attractive clusters in grape.

**h. Prevention of fruit drop**

Applications of NAA, 2,4,5-T, SADH in apple and NAA, SADH in pear at full bloom were highly effective controlling fruit drop. SADH treatments in apple proved beneficial in arresting development of water cores and cold storage scales in fruits. Post-harvest berry drop reduces the market value of grape, in certain varieties like Cheema Sahebi, Anab-e-Shahi, Dilkush etc. This can be overcome by spraying 50-100 ppm of NAA a week prior to harvest.

**i. Early Fruit harvesting**

Ethylene is the most common bioregulators used for chemical induced harvesting of fruit crops *viz.,* apple, cherry, pear, plum and grapes. In most of the fruits, pre-harvest sprays are suggested. Ethrel sprays have also resulted in uniform maturation of fruits with accelerated ripening in citrus and mango pre-harvest spray of cycloheximide facilitated an easy harvest of fruits.

**j. Yield enhancement**

PBRs have the potential to increase crop productivity by increasing root growth, photosynthetic efficiency and overall plant vigor. Semicarbazone's by using at the onset of reproductive growth i.e. at the onset of the flowering and/or fruit reproductive growth stage of the plant helps in increasing fruit yield. More recently, success has been achieved using PBRs to even out alternate bearing and increase cumulative yield for multiple alternate bearing cycles in various fruit crops like mango, apple, pear etc.

### 3. PLANT BIOREGULATORS AS WEEDICIDES

Herbicides like Dinoseb, Diquate, Paraquat, Prophan, 2,4,5-T, MCPA, Simazin and Atrazin were found more effective to control various types of weeds in the orchards of various fruit crops. High-speed diesel oil (HSD) combined with herbicides used successfully in controlling weeds in citrus orchards.

### 4. POST-HARVEST AND QUALITY IMPROVEMENT

During maturation, the last stage of development, the fruit attains full size and optimum eating quality. Ripening is the terminal period of maturation when fruit develop flavor, texture and aroma that contribute to eating quality. Endogenous/exogenous plant bioregulators play important role in growth regulation of ripening process, which is associated with a number of changes such as colour, production of volatiles, cell wall softening and enhancement in the activities of respiratory and hydrolytic enzymes.

The effectiveness of GA in retarding the pigment degradation and activity of ripening enzymes has led to commercial application of GA in the fruits. The treatment with GA was beneficial for retarding degreening in fruits as banana, mango, pear, apricot, etc. The effect of GA on delaying of maturity and ripening can be overcome by application of ethylene. Gibberellins regulate fruit quality in grapes. $GA_3$ is effective in elongating rachis of grape fruit cluster and results looser cluster when applied at pre bloom stage and increases the size of berries when applied at bloom stage to fruit setting stage.

### 5. PHYSIOLOGY AND BIOCHEMISTRY

Plant bioregulators affect the physiology of plant growth and influence the natural rhythm of a plant. Several plant bioregulators play important role in physiological processes of plant viz. ion uptake, cell elongation, cell division, sink/source regulation, enzymatic activities, protein synthesis, and photosynthetic activities. They are also helpful in tolerating abiotic stresses caused by heat, cold, salinity, drought, water logging, nutrient deficiency or toxicity, pollutants etc. and improve the plant defence mechanisms.

## PROSPECTS OF FUTURE USE OF PLANT BIOREGULATORS IN HORTICULTURE

Studies on bioregulators in horticultural crops have mainly been restricted to the subtropical, tropical and temperate regions of the world. There are no efforts have been made so far to use the plant bioregulators for sustainable fruit production in cold arid high altitudes i.e. above 3,500 m MSL, where, climate is characterized by extreme cold arid conditions with -40° Celsius temperatures in winter to +35° Celsius in summers, low annual precipitation (80-300 mm), low RH (20-40%), low atmospheric pressure (493 mm Hg), high wind velocity (8-10 km/hr), long frozen winters (5-7 months), very low partial pressure of oxygen, thin atmosphere results in heavy influx of ultra violet and infra red radiations. The Defence Institute of High Altitude Research, Leh-Ladakh has initiated some studies using plant bioregulators in fruit crops viz. apricot, apple, and seabuckthorn which are playing vital role in the socio-economic development and environmental conservations of Ladakh. Besides, realizing the importance of roots in nutrient uptake and mobilization, and plant stature, due attention is required with regards to their effects on root growth and development. Similarly, studies concerning the absorption, transport and utilization coupled with factors regulating the permeability of plant bioregulators are essential in the crop responding them. The search for bioregulators to reduce photorespiration and enhance net photosynthesis, biological and economic yields and harvest index deserve special emphasis. With the emphasis given to the horticulture and taking into consideration the immense potential, the horticulture industry commands in domestic and foreign markets, the usage of bioregulators is certainly on the rise for sustainable fruit production.

Table 1. Common, trade and chemical names of some bioregulators used in fruit crops

| Common name | Trade name / Abbreviation | Important uses |
|---|---|---|
| Abscissic acid | ABA, Abscissin II | Growth inhibition, senescence inhibition, prolonging dormancy |
| Ancymidol | A-Rest, Reducymol | Growth control |
| Benzyl adenine | BA, BAP, Verdan | Tissue culture, lateral branching, senescence inhibition, dormancy inhibition |
| Chlormequat | Cycocel, CCC | Flower initiation, growth control, sex expression, senescence retardation |
| 4-Chlorophenoxy acetic acid | 4-CPA | Improved fruit set, regulation of fruit size |
| Chlorphonium chloride | Phosphon-D | Growth inhibition |
| Diaminozide | B-9, Alar, SADH | Flower initiation, growth control, promotion of vase life, preventing fruit drop, improved fruit set, fruit ripening |
| 2,4-Dichloro phenoxy acetic acid | 2,4-D | Tissue culture, retardation of flower bud abscission, improved fruit set |
| Ethephon | Ethrel, CEPA, Florel | Flowering, sex expression, growth control, fruit ripening and post-harvest degreening |
| Gibberellic acid | $GA_3$, Gibrel, Gibsol | Flowering, seed germination, prevention of bud dormancy, senescence inhibition, sex expression, chemical thinning, retardation of fruit maturity, fulfillment of chilling requirements, and production of parthenocarpic fruits |
| Indole acetic acid | IAA | Rooting, tissue culture |
| Indole butyric acid | IBA | Rooting, tissue culture |
| Kinetin | Zeatin | Breaking dormancy, vase life enhancement, senescence inhibition |
| Maleic hydrazide | MH | Growth control, flower development, control sprouting |
| Mepiquat chloride | BAS-106 | Growth retardation |
| Morphactin | - | Growth control, morphogenesis |
| α -Naphthalene acetic acid | NAA | Growth control, flower development, tissue culture |
| β -Naphthoxy acetic acid | BNOA | Improve fruit set |
| Paclobutrazol | Bonzi, PP333, Cultar | Growth retardant or growth control |
| Triiodobenzoic acid | TIBA | Lateral branching |
| 2,4,5-trichlorophen--oxy acetic acid | 2,4,5-T | Prevention of fruit drop, improve fruit set |

Table 2. Functional Similarities of Plant Bioregulators

| Characters | Auxins | Gibberellins | Cytokinins | Inhibitors | Ethylene |
|---|---|---|---|---|---|
| Effect on cell elongation | Cause cell elongation and maximum effect just below the tip | Increase internodal length and maximum effect on internodal portion | Cause enlargement of organs for e.g. Leaf thickness | Hypocotyl elongation at low concentrations in cucumber | - |
| Effect on cell division and differentiation | Cause cell division in cambium, organ and tissue differentiation | Cause cell division | Cause cell division or cell differentiation of parenchymatous cells in higher plants | - | Promote cell division |
| Effect on rooting | Rooting of cutting, leaf and callus | - | Help in rooting in low concentrations | Helps in rooting by cofactors e.g. flavones, flavonoids, gallic acid, caumarin, chlorogenic acid | - |
| Effect on growth | Induce growth of apical parts | Growth of intact plant parts | Induces growth with the help of auxins | Induces growth at very low concentrations i.e. 0.05 µg/L in some plants | Radial and tangial growth in pea |
| Effect on flowering | Induces flowering in day neutral plants | Induces flowering in cold requiring biennial plants | Helps in transformation of vegetative tissue in to reproductive tissue | Induces flowering in short day plants for e.g. chenopodium, forbits, plumbago etc. | Induces flowering in pineapple |
| Effect on fruit set and fruit growth | Increase fruit set, fruit size and control fruit drop | Increase fruit set and fruit growth | - | Increase fruit set in apple and roses | - |
| Parthenocarpic fruit development | Induces parthenocarpic fruit development | Induces parthenocarpic fruit development | - | Induces parthenocarpic fruit development in roses | - |

Table 3. Functional Dissimilarities of Plant Bioregulators

| Characters | Auxins | Gibberellins | Cytokinins | Inhibitors | Ethylene |
|---|---|---|---|---|---|
| Precursor | Tryptophan & phenyl amine | Kaurene | Adenine & isoprene | - | Methionine |
| Place of synthesis | Apical meristem | Roots, seeds & nodes | Roots | - | - |
| Movement | Polar | Non polar | Non polar | Non polar | Non polar |

Table 4. Use of Plant Bioregulators in Horticultual Crops

| Uses | Crop | Compounds or Plant Bioregulators | Concentrations (ppm) | Remarks |
|---|---|---|---|---|
| Rooting or cuttings | Lemon, mango, guava, loquat | IBA | 500-1000 ppm | Serradix hormone powder-β is also used |
| Air layering | Guava, litchi, jackfruit, loquat, mango | IBA | 500-1000 ppm | - |
| Break dormancy | Grapes | $GA_3$ | 2-5 ppm | - |
| Promotion of vegetative growth and elongation | Many fruit plant | $GA_3$ | 100 ppm | Apply when leaves are unfolding and applied on central core |
| Induce dwarfing or growth retardation | Grapes, mango, litchi and kiwifruit | MH or CCC | 250-1000 ppm | - |
| | Pear | PP333, SADH, CCC | 250-500 ppm | - |
| Induction of flowering | Pineapple | NAA | 5-10 ppm | Sprayed on plants |
| | | Ethrel | 200-400 ppm | Sprayed on plants |
| | Mango | Ethrel | 200 ppm | 5 sprays at weeks interval on new shoot in off year |
| | | Paclobutrazol | 1ml/L/year or 1ml/m diameter of plant | - |
| | Apple | PP333 / SADH | 250-500 ppm | - |
| | Litchi | NAA | 500 ppm | - |
| | Papaya | $GA_3$ | 50 ppm | Increase femaleness |
| Blossom thinning | Peach | 3-chloro isopropyl-n-phenyl carbonate | 250-350 ppm | - |
| | Apple | Ethephan | 350 ppm | At full blooming |
| | Grapes | Sevin | 1000 ppm | - |
| | Guava | NAA or 2,4-D | 800 or 250 ppm, respectively | Applied thrice at 10 days interval in April - May |
| Increase fruit set | Citrus | NAA | 10-25 ppm | - |
| | Mango | NAA | 50 ppm | - |
| Increase fruit size | Grapes, persimmon, banana, | GA3 | 50-75 ppm | At fruit ripening |
| Ripening | Mango, pineapple, sapota, apple, banana | Ethrel | 200-500 ppm | Spray on plants induced uniform ripening |