

New generation PGRs used in fruit production

ABSTRACT

Plant hormones are small molecules derived from various metabolic pathways, which are present at a very low concentration and act either locally, at or near the site of synthesis, or in distant tissues. Plant hormone includes the new generation PGRs like brassinoids, jasmonic acid, salicylic acid, polyamines, triacontanol, 1-MCP and prohexadione – Ca. Scientist often refers to five classical plant hormones; which were identified in the early to mid 20th century. The activities of new class PGRs depend on their concentration and environmental factors affecting their absorption and plant's physiological state. PGRs have the ability to effect to effect cell division, cell structure, cell expansion, cell function and mediate environmental stress even at low concentrations. Direct application of roots, leaf, flowers, buds and shoots has been shown to enhance resistance to biotic and abiotic stress. Products of PGRs are generally employed throughout viticulture, floriculture, agriculture and horticulture to increase crop yield in sub-optimal soil and harsh environmental conditions. New class of plant hormones which play important roles in various physiological processes including seed development and germination, flower sex expression, fruit development, improvement of quality and quality of produce and resistance to various biotic and abiotic stresses.

Keywords:PGRs, Brassinosteroids, Jasmonic acid, Salicylic acid, Polyamines, Triacontanol, 1-MCP and Prohexadione – Ca.

INTRODUCTION

“Plant Growth Regulators (PGR's) are those compounds which are responsible for upregulation or downregulation of factors responsible for growth, development and other physiological processes. PGR's can be natural or synthetic. PGR modifies or controls one or more specific physiological processes. Site and action of different PGR's are different in different plants. PGR's can be grouped in 2 categories based on how long they are being used

significantly in horticulture sector. There are some PGR's which are well harnessed and used widely by farmers. These includes Auxins, Gibberellins, Cytokinins, Ethylene and Abscisic acid”(Rademacher 2015). “Apart from these there are PGRs whose efficacy and efficiency are known to us but due to technological gap they are not yet been harnessed at grass root level. These include Brassinosteroids (BR), Jasmonate (JA) and Salicylic acid (SA)” (Mani *et.al.*, 2021). “Brassinosteroids are class of plant polyhydroxysteroids which is present in almost every part of plants *i.e.* Brassicaceae” (Kumar *et.al.*, 2024). “Application of BR exhibited a decline fruit abortion and fruit fall. Increase pollen tube growth and fertilization. BR prevented premature abscission of fruit. BRs also regulate the activity of defense related enzymes which could develop strong defense mechanism against different microorganisms. It was reported found that altering the level of endogenous BRs, promotes fruit quality” (Li *et.al.*, 2010; Lieselotte *et.al.*, 2014). “Organic compound found in jasmine flower (*J. grandiflorum*) and chemical formula $C_{12}H_{18}O_3$. Can be biosynthesized from linolenic acid by the octadecanoid pathway. JA enhances embryo formation, determination and development of flowers and overall fruit set” (Hink *et.al.*, 2008). “JA and methyl jasmonate protect plants from herbivores and pest by synthesis of enzymes such as proteinase inhibitors and chitinases and volatile aldehydes and oxoacids. JA and methyl jasmonate improves the total antioxidants and phenol content” (Kohli *et.al.*, 2018). Salicylic acid ($C_7H_6O_3$) is a monohydroxy benzoic acid (type of phenolic acid and betahydroxy acid). Derived from the metabolism of salicin. SA have influence on photosynthesis, ion uptake, membrane permeability, enzyme activities, flowering and growth and development of plants.

What are Plant Growth Regulators (PGRs)?

1. PGRs are those compounds, which are responsible for up-regulation or down-regulation of factors responsible for growth, development and other physiological processes.
2. PGR's can be natural or synthetic.
3. PGR modifies or controls one or more specific physiological processes.
4. Site and action of different PGR's are different in different plants.

Classical Plant growth regulators

A. Plant Growth Promoters

1. Auxin

2. Gibberellins
 3. Cytokinin
- B. Plant Growth Inhibitor's
1. Abscisic Acid
 2. Ethylene

Table 1: New generation PGRs: Their site of synthesis, precursor and primary functions

Hormones	Site of synthesis	Precursor	Primary functions
Brs	<ul style="list-style-type: none"> ✓ Pollen ✓ Seeds and young tissues 	Castasterone	<ul style="list-style-type: none"> ✓ Promotes stem elongation, cell division ✓ Inhibit root formation and growth ✓ Induces xylem differentiation ✓ Stimulates seed germination
JA	<ul style="list-style-type: none"> ✓ All living tissues ✓ Young developing fruits ✓ Cotyledons of germinated seeds 	12-oxophytodienoic acid (OPDA)	<ul style="list-style-type: none"> ✓ Enhancement of meristem formation ✓ Induces plant defense responses ✓ Increases production of secondary metabolites with a role in plant defenses ✓ Promote regeneration of shoots and roots
SA	<ul style="list-style-type: none"> ✓ Leaves 	Phenylalanine	<ul style="list-style-type: none"> ✓ Signal in thermogenic plants ✓ Signaling hormone in plant resistance to pathogens ✓ Signaling molecule for flowering
PAs	<ul style="list-style-type: none"> ✓ All living plant cells especially actively dividing ones 	Ornithine (Put), agmatine (Spd) and arginine (Spm)	<ul style="list-style-type: none"> ✓ Enhance cell division ✓ Delays leaf senescence ✓ May help in regulate flowering ✓ Inhiits ripening and senescence

Source: Edward F. Durner (Principles of Horticultural Physiology)

New generation PGR's

1. Brassinosteroids (BR),
2. Jasmonate (JA)
3. Salicylic acid (SA)
4. Polyamines

5. Triacontanol (TRIA)
6. 1-MCP (1-Methylcyclopropene)
7. Prohexadione – Ca

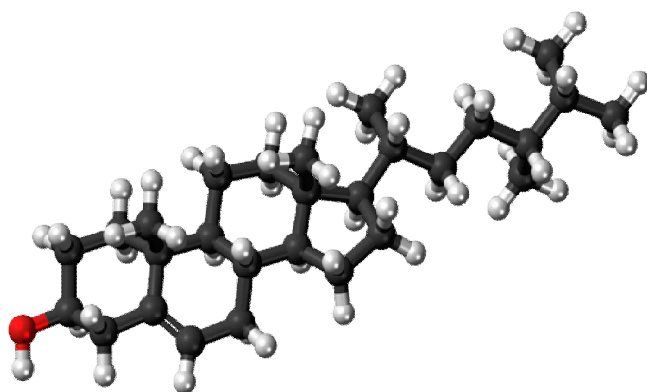
1. Brassinosteroids (BR)

“These compounds were first isolated from rape (*Brassica napus* L) pollens in 1979 by M.D. Grove and his coworkers identified the active component as brassinolide (BL) (Rao *et al.*, 2002), and subsequently in other plants” (Sasse, 1997). “Brassinosteroids collectively refer to naturally occurring 5α -cholestane steroids that elicit growth stimulation in nano or micro-molar concentrations” (Clouse & Sasse, 1998; Choe, 2004).

“Due to BRs’ growth regulator activity, this class of phytohormones is involved in a range of developmental processes, including cell division and elongation, vascular differentiation, reproductive development and the modulation of gene expression” (Bajguz, 2007).

“The main responsible for BR-mediated responses are BZR1 (BRASSINAZOLE RESISTANT 1) and BES1 (BRI1-EMS SUPPRESSOR 1), also named BZR2, the two major BR signaling pathway transcription factors, which regulate a range of genes involved in different physiological processes, such as developmental responses, protein metabolism, cellular transport and signaling, cell wall biosynthesis, chromatin and cytoskeleton components, environmental responses, and hormone responses” (Sunet *et al.*, 2010).

“BR prevented premature abscission of fruit. BRs also regulate the activity of defence related enzymes which could develop strong defence mechanism against different microorganisms. It was reported found that altering the level of endogenous BRs, promotes fruit quality” (Li *et al.*, 2010; Lieselotte *et al.*, 2014).



Campesterol

Color code:

- Carbon, C: black
- Hydrogen, H: white
- Oxygen, O: red

Figure 1: Precursor of Brassinoids (Campesterol)

Functions:

- Promotion of cell expansion and cell elongation
- Role in cell division and cell wall regeneration
- Promotion of vascular differentiation
- Pollen elongation for pollen tube formation
- Protect plants from chilling and drought stress

Effect of Brassinosteroids in fruit crops:

“Research conducted to study the effects of brassinosteroids on different developmental stages of various plant species have focused primarily on determining their impacts on seed germination and alleviating stress effects on development” (Vardhini & Rao, 1997; Leubner-Metzger, 2001; Anuradha & Rao, 2003).

“Exogenous application of brassinolide was effective in influencing all physico-chemical properties of litchi fruits. Among the treatments of brassinolide studied, brassinolide at 1 mg l⁻¹ (two-time application i.e., 15 days before and after anthesis) was identified to be superior based on suitable morphological characteristics, biochemical compositions which can be selected for further improvement with minimum fruit cracking and can be promoted for cultivation” (Ghose *et al.*, 2022).

Table 2: Application of Brassinoids in fruit crop production

Crops	Application Time	Concentration	Response/effect	Reference
Litchi	Before anthesis	1 ppm	Control of fruit cracking	Peng <i>et al.</i> (2004)
Grapes	At anthesis	0.001 ppm	Control berry drop	Isci and Gokbayaraket <i>al.</i> (2015)
Passion fruit	3 spray at 1 week interval after flowering	1 ppm	Increase yield	Gomes <i>et al.</i> (2006)
Grapes	Pea stage and veraison	0.4 mg/l	Enhanced total anthocyanin	Mani <i>et al.</i> (2021)
Sweet cherry	Pre-harvest application	0.75 mg/l	Enhanced shelf life of variety Tak-Danche Mashhad	
Sweet cherry	Beginning of fruit colour change	0.4 ppm	Early fruit ripening	Mandava and Wang (2016)
Cape gooseberry	At vegetative, flowering and fruiting stage	16 ppm	Improved physical properties and qualitative aspects of cape gooseberry	Darshan <i>et al.</i> (2022)
Kiwifruit	Root treatment	1 µm	Promoted root elongation, lateral root and root hair growth	

2. Jasmonate (JA)

“Organic compound found in jasmine flower (*J. grandiflorum*) and chemical formula $C_{12}H_{18}O_3$ isolated in 1971 from the culture filtrate of a fungus as a plant growth inhibitor. Can be biosynthesized from linolenic acid by the octadecanoid pathway. JA enhances embryo formation, determination and development of flowers and overall fruit set” (Zhang *et al.*, 2017). “JA and methyl jasmonate protect plants from herbivores and pest by synthesis of enzymes such as proteinase inhibitors and chitinases and volatile aldehydes and oxoacids. JA and MJa improves total antioxidants and phenol content” (Nafie *et al.*, 2011). Jasmonates are lipid derived compound-signals in plant stress response and development. Role in plant defence was first shown by Farmer and Ryan (1990).

Functions of Jasmonic Acid (JA)

1. Root growth/ Seed germination inhibition
2. Secondary metabolite production
3. Stimulates leaf senescence
4. Herbivory protection
5. Wound response
6. Tendril coiling in plants
7. Pollen development

Table 3: Application of Jasmonic Acid (JA) in fruit crops

Crops	Application Time	Concentration	Response/effect	Reference
Mango	Cold storage	4-10 M	Reduced chilling injury during storage at 7°C	Mani <i>et al.</i> (2021)
Guava	Matured stage	1, 10 µmol L ⁻¹	Influence on fruit ripening	Silva <i>et al.</i> (2017)
Citrus	Matured stage	At 10, 20 and 100 mM	Induce fruit abscissions, it helps for mechanical harvesting i.e. easy the detachment of fruits from tree	Hartmondet <i>al.</i> (2000)
Banana	3-4 leaf stage	1.5 mM	Defence against <i>Fusarium oxysporum</i> f.sp. Cubense race 4	Sun <i>et al.</i> (2013)
Mandarins	Dipping	0.10 mM	Control post harvest fungal decay (<i>Penicillium digitatum</i>)	Guo <i>et al.</i> (2014)
Grapevine	Spraying	5.00 mM	Control post harvest fungal decay (<i>Erysiphaenecator</i>)	Belhadj <i>et al.</i> (2006)
Pomegranate	Dipping	0.01-0.1 mM	Increasing of total phenols, anthocyanins	Sayyari <i>et al.</i> (2011)
Strawberry	At the time of flowering	0.50 mM	Improved fruit weight and total yield per plant	Darshan <i>et al.</i> (2022)

3. Salicylic Acid (SA) :

“Salicylic acid (C₇H₆O₃) is a monohydroxy benzoic acid (type of phenolic acid and betahydroxy acid). SA derived from the metabolism of salicin. SA has influence on photosynthesis, ion uptake, membrane permeability, enzyme activities, flowering and growth and development of plants” (Mani *et al.*, 2021).

“SA is colorless crystalline acid; it has influence on photosynthesis, ion uptake, enzyme activities, flowering and growth & development of plants. SA effectively reduced fruit decay, chilling injury, improves fruit firmness and maintained TSS. It is involved in the systemic acquired resistance (SAR) in which a pathogenic attack in one part of the plant induces resistance in other parts” (Kohli *et al.*, 2018).

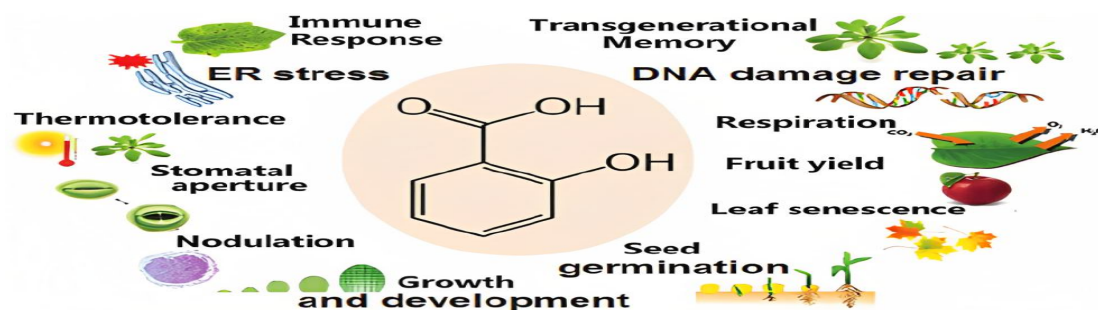


Figure 2: Role of salicylic Acid

Table 4: Application of Salicylic Acid in fruit crops

Crops	Application Time	Concentration	Response/Effect	Reference
Litchi	Mature fruit	1.0 mM	Reduce pericarp browning, weight loss, decay and maintain anti-oxidant capacity	Kumar <i>et al.</i> (2013)
Plum	Post harvest treatments	1.5 mM	Reduced chilling injury, respiration rate, ethylene rate, disease incident	Darshan <i>et al.</i> (2022)
Pomegranate	Post harvest treatments	0.4-1 mM	Reduced chilling injury, improved TSS, total phenolic compounds and reduced acidity	Mirdehgham and Ghotbi(2014)
Peach	Pre-harvest period	2 mM	Increase fruit weight, firmness, antioxidant, phenol content and titrable acidity	Erogul and Özsoydan(2020)
Strawberry	Spray on the vegetative tissues and fruit every 14 days	3 mM	Highest fruit yields and lowest percentage of gray mould	Mohamed <i>et al.</i> (2017)
Grapefruit	Post harvest spray	12mM	High antioxidants, total carotenoids, total limonin contents, minimum chilling injuries and fruit rots	Ahmed <i>et al.</i> (2015)

4. Polyamines (PAs)

Polyamines are strongly basic protein based substances of low molecular weight that exist either free or bound in all plant cells. Biological compounds having variable hydrocarbon chains. Low molecular weight. Aliphatic nitrogen groups. containing two or more amino groups. Range from micromolar to millimolar. All polyamines are positively charged and bind strongly to negatively charged enzymes. The main polyamines in plants include putrescine (Put), spermidine (Spd), and spermine (Spm). Interfere with ethylene biosynthesis lead to a less ripe fruit - quality control in post harvest handling. Cell division, embryo development, delay leaf senescence by preventing chlorophyll loss, defense mechanism against abiotic stress. Polyamines are also implicated in regulation of the flowering process.

Role of Polyamines in plants

1. Cell division
2. Embryo development
3. Flower development
4. Regulate fruit ripening
5. Reduce physiological weight loss

6. Anti-senescence agent
7. Defense mechanism against abiotic stress

Table 5: Application of Polyamines (PAs) in fruit crops:

Crops	Application Time	Concentration	Response/Effect	Reference
Mango	At pea stage and 20 days after first spray	150 ppm	Maximum number of fruits/panicle, number of fruits/tree and fruit yield and maximum fruit weight	Venu and Ramdevputra (2018)
Papaya	After harvesting	1 mM	Inhibition fruit softening, rate of ethylene production and respiration, total sugars and peel color development	Purwokoet <i>al.</i> (2002)
Apple	Spraying	0.25 mM	Highest percentage of fruit set	Sayyad-Amin <i>et al.</i> (2018)
Citrus	At full bloom	0.01 mM	Maximum fruit set	Saleem <i>et al.</i> (2008)
Pistachio nut	Full bloom stage	1 mM	Maximum yield per shoot	Khezriet <i>al.</i> (2010)
Strawberry	Foliar application at 4-5 fully expanded leaves	1.5 mM	Maximum truss number and yield/plant	Movahed <i>et al.</i> (2012)

5. Triacontanol (TRIA)

It is found from Alfaalfa (*Medicago sativa* L) by Ries *et al.* in 1977. Also known as melissyl alcohol or myricyl alcohol. It is found in plant cuticle waxes (Rice) and in beeswax. Induce the production of flowering. Used to help plants suffering nutrient and growth deficiencies. TRIA improves the rate of cell division in a plant that produces larger roots and shoots. Enhance photosynthesis and plant metabolism. "Triacontanol has been reported to enhance plant tolerance to various abiotic stresses, such as drought, salinity, and extreme temperatures. It can help regulate the plant's physiological responses to stress, reducing the negative impact and improving plant survival rates, modulating hormone levels: triacontanol can influence hormone metabolism and signaling pathways in plants. It has been found to increase the levels of plant growth regulators such as indole-3-acetic acid (IAA) and cytokinins, which play crucial roles in plant growth and development, enhancing nutrient uptake: triacontanol has been shown to improve nutrient uptake efficiency in plants. It can enhance the activity of membrane transporters involved in the uptake of essential minerals, leading to increased nutrient absorption and improved nutrient status in plants, and stimulating

flowering and fruiting: triacontanol has been found to promote flowering and enhance fruiting in certain plant species. It can induce the expression of genes related to flower and fruit development, leading to earlier flowering, increased flower and fruit set, and improved fruit quality”. (Waqas et al. 2016; Naeem et al. 2009, 2019; Zaid et al. 2019). “TRIA regulates gene expression, which can either suppress or amplify stress reactions” (Perveen et al. 2017; Islam et al. 2020).

Role of Triacontanol (TRIA):

1. Increase root length, fresh/dry mass
2. Increase shoot length, fresh/dry mass
3. Increase leaf area per plant
4. Higher photosynthetic efficiency
5. Increases nutrient accumulation
6. Increase yield and yield attributes
7. Improve nitrogen fixation
8. Enhanced translocation and accumulation of sugar

Table 6: Application of Triacontanol (TRIA) in fruit crops:

Crops	Application Time	Concentration	Response/Effect	Reference
Strawberry	Two spray were done; 1 st at 3-4 leaf stage & 2 nd at 15 days after 1 st application	10 µM	Increase in vegetative growth characters, duration of flowering, number of flowers and fruit yield per plant	Rehman <i>et al.</i> (2017)
		100 and 150 ppm	Best in flowering and fruiting parameters of strawberry	Singh <i>et al.</i> (2020)
Mango	Two foliar spray at pea and marble stage of fruit	750 mg/l	Minimum physiological loss in weight of fruits	Gaikawad <i>et al.</i> (2022)
	Foliar spray to panicles at full bloom, pea size stage and at marble size stage of fruits	300 ppm	Highest fruit set and minimum fruit drop	Kumar <i>et al.</i> (2021)
Apple	Sprayed at three times (i) At bud stage (ii) three weeks after fruit set (iii) two months after second spray	10 ppm	Highest fruit set and minimum fruit drop	Zubair <i>et al.</i> (2017)

6. 1-MCP (1-Methylcyclopropene) :

1-MCP is a novel compound that can prolong the shelf life of fresh produce by inhibiting the action of ethylene. It is registered under trade name of SmartFresh™ or EthylBloc™ by Agrofresh Inc. / Rohm and Haas Company (Philadelphia, USA). 1-MCP is a highly volatile gas, thus commercially it is available in an encapsulated form in α -cyclodextrin (CD). The appropriate amount of water or KOH buffer are required as a trigger to release this encapsulated 1-MCP gas molecules. The commercialization of 1-MCP for edible horticulture products was approved in 2002 by EPA. Apples were the first crop to receive registration for receiving 1-MCP treatment commercially.

Role of 1-MCP:

1. Interact with ethylene sensitive site
2. Reduces the respiration, delays aging and coloration
3. Delay chlorophyll degradation
4. Delays fruit softening and improves quality
5. Decreases storage disorders
6. Keep the original flavor for longer time

Table 7: Application of 1-MCP (1-Methylcyclopropene) in fruit crops

Crops	Application Time	Concentration	Response/Effect	Reference
Sapota	After harvesting	100 mL L ⁻¹	Extending the shelf life and increasing the marketable fruits	Thakriya <i>et al.</i> (2022)
Mango		100 or 500 mL L ⁻¹	Extend the shelf life and maintain quality of fruit for weeks on ambient storage condition	Ayele <i>et al.</i> (2012)
Pitahaya fruits		600 mg L ⁻¹	Reduce ethylene action, slowing the ripening of dragon fruits	Deaquizet <i>et al.</i> (2014)
Grapes		1 mL L ⁻¹	Reduces respiration and ethylene production	Li <i>et al.</i> (2015)
Pomegranate		1 mL L ⁻¹	Reduced development of superficial scald incidence and reduced PPO enzyme activity	Defilippi <i>et al.</i> (2006)

7. Prohexadione – Ca

The compound acts as a structural mimic of 2-oxoglutaric acid. Prohexadione- Ca is relatively short-lived and possesses very favorable toxicological and ecotoxicological features. It contains Carboxylic group. It is anti- gibberellins.

Table 8: Application of Prohexadione – Ca in fruit crops

Crops	Application Time	Concentration	Response/Effect	Reference
Apple	Spraying at bloom stage	125 mg L ⁻¹	Increased fruit set and control vegetative growth and reduce the incidence and severity of fire blight	Greene (2007)
	Spraying at bloom stage	250 mg L ⁻¹	Suppression of additional shoot growth and reduce crop load	Byers <i>et al.</i> (2004)
Raspberry	Foliar spray in April-May	100 ppm (1 st spray) and 200 ppm (2 nd spray) at a 3 week interval	Increasing the number of nodes per meter of cane, increases fruit quality, yield per cane, total antioxidant capacity, total phenolics and anthocyanin contents	Poledica <i>et al.</i> (2012)
Sweet cherry	Foliar spray at new growth reached about 5-10 cm	500 mg L ⁻¹	Controlling vegetative growth and establish acceptable growth control without negative effect on bloom return, fruit yield and fruit quality	Jacyna and Lipa (2010)

Role of Prohexadione-Ca :

1. It reduces ethylene formation.
2. It reduce alternate bearing
3. It act as alternative for paclobutrazol.
4. It reduces longitudinal shoot growth by blocking dioxygenases
5. It inhibit excessive vegetative growth in fruit trees and other crop plants.

7. Chloro-4-pyridyl)-N'-phenylurea(CPPU).

“Forchlorfenuron, also known as N-(2-Chloro4-pyridyl)-N'-phenylurea (CPPU), is a potent cytokinin-like plant growth regulator that encourages cell division, chlorophyll production, and cell development. Additionally, it speeds up fruit growth and promotes fruit set”

(Zeng et al. 2016). “CPPU increases periclinal cell division, resulting in berries that are rounder and/or oval in shape (kiwifruit and grapes). It also causes a delay in grape maturation and red colour development, as well as an increment in rachis size and pedicel thickness. In addition to its general effects, the storage life of grapes was increased as a result of the pre-harvest application of CPPU” (Marzouk, Kassem 2011). “The spray of CPPU in the pomegranate resulted in improved Total Soluble Solids and total sugar content” (Supe, Marbhal 2008). In guava, when CPPU was applied, it increased TSS, ascorbic acid and total acid content, and fruit firmness (Sabaghnia, Nahandi 2019). The effects of foliar applications of 3 and 4 ppm Swell (CPPU) at fruit set were significantly superior in mango; however, it did not influence the biochemical properties of the fruit, such as total soluble solids, titratable acids, or sugar content (Pujari et al. 2016). At petal fall stage, the application of CPPU @ 5 ppm as dipping application obtained a significantly higher average fruit yield of 54.20 kg per vine. Similarly, maximum average fruit size (77.75 mm length and 53.74 mm diameter) and fruit weight (121.99 g) was recorded (Banyal, Banyal 2020). In another study of kiwi, fruits that were dipped for 10 seconds in an aqueous solution of 10 ppm CPPU at petal fall and again 30 days later grew 20-70 g larger than control fruits (Pramanick et al. 2015). The kiwi fruit quality and taste were harmed by high CPPU dosages, however. When all quality indicators are taken into account, 10 ppm CPPU produced the best fruit quality after storage.

Brief Review of Some Research Work

Brassinosteroid

Mango

Ramani et al. (2016) noted that application of @ 1.0 ppm 28-homobrassinolide at new leaf initiation stage can be sprayed to get significant increase in shoot length (72.37 cm), shoot girth (71.73 mm), fruits set per panicle (7), fruits retained per panicle (1.84), number of fruit per tree (430.76) and yield per tree (134.93) and minimum days taken for 100% flowering (103 days) in mango cv. Kesar.

Custard apple

Mustafa and Kotb (2018) found that combined application of 1000 mg /L GA3 plus 0.5 mg /L BRs had positive effect and therefore can be recommended for spray on sugar apple in order to obtain seedless fruit with high quality, so, it can be used as an alternative to hand pollination.

Jasmonic Acid

Acid lime

Yamini et al. (2021) studied jasmonic acid @ 3 ppm showed better performance in fruit set (20.98%), number fruits per plants (1234), fruit yield (62.02 kg/plant), fruit breadth (31.36 mm), fruit juice contents (46.16%), fruit volume (52.65 cc) was significant over untreated control.

Salicylic Acid

Papaya

Devarakonda et al. (2020) noted that application of salicylic acid @ 150 ppm twice at 45 and 120 DAT was seen on significantly highest number of leaves at 150 DAT (33.87), 180 DAT (35.72), 210 DAT (43.33) and 240 DAT(43.73) along with total chlorophyll content, chlorophyll 'a' and chlorophyll 'b' content. Further minimum number of days taken for initiation of flowering (112.67 DAT) and days taken for 50% flowering (128.67 DAT) and days taken for first fruit initiation (145.50 DAT) were significantly with the application of Salicylic acid@ 100 ppm at 45 DAT and 120 DAT(112.67 DAT and 128.67 DAT). Almost a similar trend was observed in Salicylic acid @ 150 ppm at 45 DAT and 120 DAT were height yield (116.06 tons ha⁻¹) in papaya.

Polyamines

Pistachio nut

Khezriet al. (2010) reported that minimum blank nuts (10.3 %) and deformed nuts (5.7 %) were observed in Spm 1.0 mM and Spm 0.1 mM, respectively at One week before full bloom. Whereas, application of Spm1.0 mM at two weeks after full bloom gave minimum blank nuts (12.3 %) and deformed nuts (4.5 %) in pistachio nut.

Mango

Venu and Ramdevputra (2018) revealed that foliar application of putrescine @ 150 ppm at full bloom stage gave minimum physiological weight loss (13.04 % and 13.06 %) and spoilage (8.57 % and 8.71 %), whereas maximum days to ripening (16.47 and 16.68) and shelf life (20.53 and 20.73 days) during both year of experiment in Kesar mango. Furthermore, minimum TSS (15.57 and 15.60⁰Brix), reducing sugar (5.07 % and 5.15 %), total sugar (14.48 %

and 14.55 %) and maximum ascorbic acid (17.89 and 17.85 mg/100g) were recorded under same treatment.

Apple

Sayyad-Amin *et al.* (2018) revealed that maximum june fruit set (61.72 %), final fruit set (34.72 %) and index of self-incompatibility (2.41) were recorded under foliar application of spermidine @ 0.25 mM between bud swollen and flower opening stage, while maximum initial fruit set 75.63 % and 74.60 % were recorded with SICS @ 1 ppm and spermine @ 0.05 mM treatment, respectively in apple cv. Golden Delicious. Maximum yield were recorded with SICS @ 2 ppm (2349 g) followed by spermidine @ 0.25 mM (1990.8 g).

Triacantanol

Strawberry

Singh *et al.* (2020) stated that maximum plant height at 120 days (17.20), number of leaves per plant at 120 days (15.13), plant spread at 120 days (21.55 cm) and petiole length at 120 days (18.09 cm) values for vegetative parameters were recorded in Triacantanol (150 ppm) + Pusa hydrogel- 50 gm. Whereas maximum number of flowers per plants (12.32), fruit length (5.05 cm) minimum days taken to first flower (54.96), days taken to first fruit (69.77) were recorded in Triacantanol (150 ppm) + CCC (50 gram) + Pusa hydrogel (50 gm) for two successive years and pooled were recorded in Triacantanol (150 ppm) + Cycocel (500 ppm) + Pusa hydrogel (50 gram).

Mango

Kumaret *al.* (2021) revealed that among the treatments @ 1 ppm BRs and 300 ppm triaacantanol recorded maximum increase in length of fruit (8.98 cm), girth of fruit (4.95 cm), weight of fruit (182.99 g), volume of fruit (191.02 ml), Mesocarp-pulp (135.31 g), stone weight (22.68 g), peel weight (22.27 g), Pulp: Peel ratio (6.05) and Pulp peel stone percentage (25.43 %) in mango cv. Dashehari.

1-MCP

Sapota

Thakriyaet *al.* (2022) studied on different concentration of 1-MCP and stored under ambient temperature and low temperature (12.0 ± 0.5 °C). The result revealed that the sapota

fruits fumigated with 1-MCP @ 100 nL L⁻¹ and stored under low temperature (12.0 ± 0.5 °C) had recorded maximum marketable fruits (75.61 %), shelf life (22.39 days), maximum fruit firmness (1.91 kg cm⁻²) and minimum PLW (7.63 %), spoiled fruit (24.40 %), ethylene production (6.53 ppm) and respiratory activity (52.94 mg CO₂ kg⁻¹ hr⁻¹) at 20th day of storage.

Raspberry

Milenaet al. (2012) stated that application of Prohexadione Ca with 100 ppm (1st application) and 200 ppm (2nd application) at 3week interval result reducing vegetative growth length of canes (211 cm), cane diameter (5.60 mm) and increasing number of fruiting laterals per cane (14.3), number of drupelets per fruit (106), yield per cane (881 g) and soluble solids content (11.3 %) in raspberry.

Conclusion:

Numerous PGRs based on chemicals and hormones have been applied in the field to increase the stress tolerance and production of horticultural crops. The molecular mechanisms behind the actions of the wide range of plant growth regulators used to boost plant development, defense, growth, and productivity are yet unknown. Additionally, a number of criteria, such as field stability, inertness, cost-effectiveness, ease of application, and adaptability to a range of pressures, are necessary for their commercialization. Given the constantly changing and unexpected climatic conditions, future research may focus on developing combined-based growth regulators technology that incorporates a mix of varied plant growth regulators that can better handle several stress settings and have a significant impact on growth and productivity. The financial viability of commercializing plant growth regulators from the perspectives of the agrochemical industry and the final consumers, smallholder farmers, is another topic that requires thorough investigation. In order to ensure long-term horticultural maintainability, the field of plant growth regulator-based research is still in its infancy and may be investigated with the specific goal of developing a highly adaptable and successful innovation that can be directly applied on the farmer's field. The review attests to the qualitative improvement in fruit quality brought about by the interaction of PGRs and micronutrients.

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Details of the AI usage are given below:

- 1.
- 2.
- 3.

References:

Ahmed W, Ahmed S, Ali L, Hussan I. Effects of pre-harvest spray of salicylic (SA) and methyl jasmonate (MeJA) on the phytochemicals and physiological changes during the storage of grapefruit Cv. ray ruby. *International Journal of Biosciences*. 2015;6(1):269-282.

Anuradha S, Rao SSR. Application of brassinosteroids to rice seeds (*Oryza sativa* L.) reduced the impact of salt stress on growth, prevented photosynthetic pigments loss and increased nitrate reductase activity. *Plant Growth Regulation*. 2003;40:29-32.

Ayele L, W/Tsadik K, Abegaz K, Yetneberk S. Postharvest Ripening and Shelf Life of Mango (*Mangifera indica* L.) Fruit as Influenced by 1-Methylcyclopropene and Polyethylene Packaging. *Ethiopian journal of agricultural sciences*. 2012;22:26-44.

Baba TR, Ali A, Kumar A, Husain, M. Effect of exogenous application of salicylic acid and triacontanol on growth characters and yield of strawberry. *The Pharma Innovation*. 2017;6(11):274-279.

Bajguz A. Metabolism of brassinosteroids in plants. *Plant Physiology and Biochemistry*. 2007;45:95-107.

Banyal AK, Banyal SK. Forchlorfenuron (CPPU): a promising plant growth regulator augments fruit size, fruit weight, quality and yield of kiwifruit (*Actinidia deliciosa*) cv. 'Hayward'. *International Journal of Current Microbiology and Applied Sciences*. 2020;9:2091–2101.

Belhadj A, Saigne C, Telef N, Cluzet S, Bouscaut J, Corio-Costet, MF, Mérillon JM. Methyl jasmonate induces defense responses in grapevine and triggers protection against *Erysiphe necator*. *Journal of Agricultural and Food Chemistry*. 2006;54(24):9119-9125.

Byers RE, Carbaugh, DH Combs LD, Prohexadione-calcium Suppression of Apple Tree Shoot Growth as Affected by Spray Additives. *Hort Science*. 2004;39(1):115-119.

Choe S. Brassinosteroid biosynthesis and metabolism. In: Davies, P.J. (ed). *Plant hormones: biosynthesis, signal transduction, action*. Kluwer Academic Publishers, Dordrecht, The Netherlands. 2004;156-178.

Darshan D, Hota D, Reema Devi, Shukla JK. Micronutrients and plant growth regulators affecting the yield and quality of fruit crops: A review. *Emergent Life Sciences Research*. 2022;8(2):92-103.

Deaquizl YA, Álvarez-Herrera J, Fischer G. Ethylene and 1-MCP affect the postharvest behavior of yellow pitahaya fruits (*Selenicereus megalanthus* Haw.) *Agronomía Colombiana*. 2014;32(1):44-51.

Defilippi BG, Whitaker BD, Hess-Pierce BM, Kader AA. Development and control of scald on wonderful pomegranates during long-term storage. *Postharvest Biology and Technology*. 2006;41:234-243.

Devarakonda S, Madhumathi C, Umamahesh V, Mukunda L, Lakshmi M, Bhaskar VV, Rajasekharam T. Growth, flowering and yield Response of papaya (*Carica papaya* L.) cv. red lady to exogenous application of salicylic acid and Jasmonic acid. *The Pharma Innovation*. 2020;9(5):160-165.

Durner EF. *The Plant Hormones: Principles of Horticultural Physiology*, 2013;pp-14.

Erogul D, Özsoydan I. Effect of pre-harvest salicylic acid treatments on the quality and shelf life of the 'Cresthaven' peach cultivar. *Folia Horticulturae*. 2020;32(2):221-227.

Farmer EE, Ryan, CA. Interplant communication: airborne methyl jasmonate induces synthesis of proteinase inhibitors in plant leaves. *Proceedings of the National Academy of Sciences*. 1990;87(19):7713-7716.

Gaikawad GB, Patil MB, Nainwad RV, Hinge AM, Patil LP. Effect of plant growth regulators and chemicals on fruit setting and yield of mango (*Mangifera indica* L.) var. Kesar. *The Pharma Innovation Journal*. 2022;11(8):2218-2219.

Ghose T, Panja P, Sau S, Datta P. Role of Brassinolide in Fruit Growth, Development, Quality and Cracking of Litchi Cv. Bombai Grown in New Alluvial Zone of West Bengal. *International Journal of Bio-resource and Stress Management*. 2022;13(5):507-512.

Gomes MDMA, Campostrini E, Leal NR, Viana A, Ferraz TM, Nascimento-Siqueira L, Rosa RCC, Netto AT, Nunez-Vazquez M, Zullo MAT. Brassinosteroid analogue effects on the yield of yellow passion fruit plants (*Passiflora edulis* f. *fiavicarpa*). *Scientia Horticulturae*. 2006;110:235-240.

Greene DW. The Effect of Prohexadione-calcium on Fruit Set and Chemical Thinning of Apple Trees. *Hort Science*. 2007;42(6):1361-1365.

Grove MD, Spencer GF, Rohwedder WK, Mandawa N, Worley JF, Warthen, Jr. JD, Steffens GL, Flippen-Anderson JL, Cook Jr JC. Brassinolide, a plant growth-promoting steroid isolated from *Brassica napus* pollen. *Nature*. 1979;281:216-217.

Guo J, Fang W, Lu H, Zhu R, Lu L, Zheng X, Yu T. Inhibition of green mold disease in mandarins by preventive applications of methyl jasmonate and antagonistic yeast *Cryptococcus laurentii*. *Postharvest Biology and Technology*. 2014;88:72-78.

Hartmond U, Yuan R, Burns JK, Grant A. Citrus Fruit Abscission Induced by Methyl-jasmonate. *Journal of the American Society for Horticultural Science*. 2000;125(5):547-552.

Hink, M.A.; Shah, K.; Russinova, E.; De Vries, S.C. and Visser, A.J.W.G. (2008). Fluorescence fluctuation analysis of Arabidopsis thaliana somatic embryogenesis receptor-like kinase and brassinosteroid insensitive 1 receptor oligomerization. *Biophys Journal*, **94**:1052–1062.

Isci B, Gokbayrak Z. Influence of brassinosteroids on fruit yield and quality of table grape 'Alphonse Lavallée'. *Vitis*. 2015;54(1):17-19.

Islam S, Zaid A, Mohammad F. Role of triacontanol in counteracting the ill effects of salinity in plants: A review. *Journal of Plant Growth Regulation*. 2020;40:1-10

Jacyna T, Lipa T. Direct and apparent residual effects of prohexadione- calcium applied to young cropping sweet cherry trees. *Acta agrobotanica*. 2010;63(1):87-92.

Khezri M, Talaie A, Javanshah A, Hadavi F. Effect of exogenous application of free polyamines on physiological disorders and yield of 'Kaleh-Ghoochi' pistachio shoots (*Pistacia vera* L.). *Scientia Horticulturae*. 2010;125(1):270-276.

Kohli SK, Handa N, Bali S, Arora S, Sharma A, Kaur R, Bhardwaj R. Modulation of antioxidative defense expression and osmolyte content by co-application of 24-epibrassinolide and salicylic acid in Pb exposed Indian mustard plants. *Ecotoxicology and Environmental Safety*. 2018;147:382-393.

Kumar A, Rajan R, Pandey K, Ramprasad RR, Kaur G, Vamshi T, Singh T. Impact of new generation plant growth regulators on fruit crops - A review. *Horticultural Science (Prague)*. 2024;51(1):1-22.

Kumar D, Mishra DS, Chakraborty B, Kumar P. Pericarp browning and quality management of litchi fruit by antioxidants and salicylic acid during ambient storage. *Journal of Food Science and Technology*. 2013;50(4):797-802.

Kumar P, Singh V, Johar V, Kumar A, Kadlag SS. Uses of Plant Growth Regulators and Biofertilizers in Fruit Crops: A Review. *International Journal of Environment and Climate Change*. 2022;12(11):314-326.

Leubner-Metzger G. Brassinosteroids and gibberellins promote tobacco seed germination by distinct pathways. *Planta*. 2001;213:758-763.

Li J, Li Y, Chen S, An L. Involvement of brassinosteroid signals in the floral-induction network of Arabidopsis. *Journal of Experimental Botany*. 2010;61(15):4221-4230.

Li L, Kaplunov T, Zutahy y, Daus A, Porat R, Lichter A. The effects of 1-methylcyclopropane and ethylene on postharvest rachis browning in table grapes. *Postharvest Biology and Technology*. 2015;107:16-22.

Lieselotte DB, Hofte M, De Vleeschauwer D. Connecting growth and defense: the emerging roles of brassinosteroids and gibberellins in plant innate immunity. *Molecular Plant*. 2014;7:943-959.

Mandava B, Wang Y. Effect of brassinosteroids on cherry maturation firmness and fruit quality. *Acta Horticulturae*. 2016;1139:451-458.

Mani A, Murmu DK, Krishna B. New-Generation Plant Growth Regulators (PGR's) in Fruit Crops. Agriculture & Food E-Newsletter. 2021;3(2). ISSN: 2581-8317.

Marzouk HA, Kassem HA. Improving yield, quality, and shelf life of Thompson seedless grapevine by preharvestfoliar applications. Scientia Horticulturae, 2011;130:425-430.

Mirdehghan SH, Ghotbi F. Effects of Salicylic Acid, Jasmonic Acid, and Calcium Chloride on Reducing Chilling Injury of Pomegranate (*Punica granatum* L.) Fruit. Journal of Agricultural Science and Technology. 2014;16(1): 163-173.

Mohamed RA, Abdelbaset AK, Abd-Elkader DY. Salicylic acid effects on growth, yield, and fruit quality of strawberry cultivars. Journal of Medicinally Active Plants, 2018;6:1-11.

Mohamed RA, Al-KharpotlyA, Abd-Elkader DY. Salicylic acid effects on growth, yield, and fruit quality of strawberry cultivars. Journal of Medicinally Active Plants. 2017;6(2):1-11.

Mostafa LY, Kotb HRM. Effect of Brassinosteroids and Gibberellic acid on parthenocarpic fruit formation and fruit quality of Sugar Apple (*Annona squamosa* L.). Middle East Journal of Agriculture Research. 2018;07(04):1341-1351.

Movahed N, Eshghi S, Tafazoli E, Jamali B. Effects of polyamines on vegetative characteristics, growth, flowering and yield of strawberry ('Paros' and 'Selva'). Acta Horticulturae. 2012;926(926):287-294.

Naeem M, Ansari AA, Aftab T, Shabbir A, Alam MM, Khan MMA, Uddin M. Application of triacontanol modulates plant growth and physiological activities of *Catharanthus roseus* (L.). International Journal of Botany Studies, 2019;4:131–135.

Naeem M, Khan MMA, Siddiqui MH. Triacontanol stimulates nitrogen-fixation, enzyme activities, photosynthesis, crop productivity and quality of hyacinth bean (*Lablab purpureus* L.). Scientia Horticulturae. 2009;121:389-396

Nafie E, Hathout T, Al-Mokadem AM. Jasmonic acid elicits oxidative defense and detoxification systems in *Cucumis melo* L. cells. Brazilian Journal of Plant Physiology. 2011;23(2):161-174.

Patel MK, Panda C, Senapati S. Influence of new generation PGRs on physical parameter of mango (*Mangifera indica* L.) cv. Dashehari. The Pharma Innovation Journal. 2021;10(10):299-302.

Peng J, Tang XD, Feng HY. Effects of brassinolide on the physiological properties of litchi pericarp (*Litchi chinensis* cv. nuomoci). Scientia Horticulturae; 2004;101:407-416.

Perveen S, Iqbal M, Parveen A, Akram MS, Shahbaz M, Akber S, Mehboob A. Exogenous triacontanol-mediated increase in phenolics, proline, activity of nitrate reductase, and shoot k+ confers salt tolerance in maize (*Zea mays* L.). Brazilian Journal of Botany, 2017;40:1–11.

Poledica MM, Milivojević MJ, Radivojević DD, DragišićMaksimović JJ. Prohexadione-Ca and young cane removal treatments control growth, productivity, and fruit quality of the Willamette raspberry. Turkish Journal of Agriculture and Forestry. 2012;36:680-687.

Pramanick KK, Kashyap P, Kishore DK, Shajtma YP. Effect of summer pruning and CPPU on yield and quality of kiwi fruit (*Actinidia deliciosa*). Journal of Environmental Biology, 2015;36:351.

Pujari KH, Malshe AV, Zagade VV, Shedje MS. Effect of Swell (CPPU) on fruit retention, fruit quality and yield of “Alphonso” mango. Plant Archives. 2016;16:649-653.

Purwoko BS, Susanto S, Novita T. Studies on the physiology of polyamines and ethylene during ripening of banana and papaya fruits. *Acta Horticulturae*. 2002;575: International Symposium on Tropical and Subtropical Fruits.

Rademacher W. Plant growth regulators: backgrounds and uses in plant production. *Journal of Plant Growth Regulation*. 2015;34: 845-872.

Ramani MM, Patel CR, Sharma KM, Amarcholi, JA, Patel AH. Effect of 28-homobrassinolide and shoot thinning on vegetative growth, flowering and yield of mango cv. Kesar. *Advancements in life sciences*. 2016;5(17):7097-7099.

Rao RSS, Vardhini VB, Sujata E, Anuradha S. Brassinosteroids- A new class of phytohormones. *Current science*. 2002;82(10):1239-1245.

Ries S, Wert VF, Sweeley CC, Leavitt RA. Triacntanol: a new naturally occurring plant growth regulator. *Science*. 1977;195:1339-1341.

Sabaghnia Z, Nahandi F. Effects of Forchlorofenuron (CPPU) treatment on fruit properties in the fruit of common guava. In: *Annales Universitatis MariaeCurieSklodowska, section C-Biologia*, 2019;72:7-14.

Saleem BA, Malik AU, Anwar R, Farooq M. Exogenous application of polyamines improves fruit set, yield and quality of sweet oranges. *Acta Horticulturae*. 2008;774:187-194.

Sasse JM. Recent progress in brassinosteroid research. *Physiologia plantarum*. 1997;100:696-701.

Sayyad-Amin P, Davarynejad GH, Abedy B. The effect of polyamines and SICS on the compatibility, fertility and yield indices of apple cv. Golden Delicious. *Advances in Horticultural Science*. 2018;32(2):213-219.

Sayyari M, Babalar M, Kalantari S, Martínez-Romero D, Guillén F, Serrano M, Valero D. Vapour treatments with methyl salicylate or methyl jasmonate alleviated chilling injury and enhanced antioxidant potential during postharvest storage of pomegranates. *Food Chemistry*. 2011;124: 964-970.

Silva BMP, Binoti RM, Cia P, Valentini SRT, Bron IU. Ripening of 'Kumagai' guavas and anthracnose control as affected by methyl Jasmonate. *Post Harvest Technology*. 2017;76(1):167-176.

Singh S, Mishra S, Jamwal SS, Bahadur V. Effect of Pusa Hydrogel and Plant Growth Regulators on Vegetative Growth, Flowering and Fruiting of Strawberry (*Fragaria x ananassa* Dutch) Cv. Chandler. *International Research Journal of Pure and Applied Chemistry*. 2020;21(6):17-24.

Sun D, Lu X, Hu Y, Li W, Hong K, Mo Y, Cahill, DM. Xie J. Methyl jasmonate induced defense responses increase resistance to *Fusarium oxysporum* f. sp. *cubense* race 4 in banana. *Scientia Horticulturae*. 2013;164:484-491.

Sun Y, Fan XY, Cao DM, Tang W, He K, Zhu JY, He JX, Bai MY, Zhu S Oh E. Integration of Brassinosteroid Signal Transduction with the Transcription Network for Plant Growth Regulation in *Arabidopsis*. *Developmental Cell*. 2010;19:765-777.

Supe VS, Marbhal SK. Effect of plant growth substances on fruit quality of pomegranate. *Asian Journal of Horticulture*. 2008;3:133-135.

Thakriya HR, Tandel YN, Saravaiya SN, Ahlawat TR, Viyol SH. Influence of 1-MCP and storage conditions on physical properties of sapota. *The Pharma Innovation Journal*. 2022;11(1):10-15.

Vardhini BV, Rao SSR. Effects of brassinosteroids on salinity induced growth inhibition of groundnut seedlings. *Indian Journal Plant Physiology*. 1997;40:156-157.

- Venu A, Ramdevputra MV. Effect of Polyamines and NAA Application on Quality and Shelf Life of Mango (*Mangifera indica* L.) cv. Kesar. *International Journal of Current Microbiology and Applied Sciences*. 2018;7(5):2906-2911.
- Waqas M, Shahzad R, Khan AL, Asaf S, Kim YH, Kang SM, Lee IJ. Salvaging effect of triacontanol on plant growth, thermotolerance, macro-nutrient content, amino acid concentration and modulation of defense hormonal levels under heat stress. *Plant Physiology and Biochemistry*. 2016;99:118–125.
- Yamini S, Huchche AD, Dhongade A, Thirugnanavel A, Kumar V. Effect of Foliar Application of Growth Regulators and Nutrients on Fruit Retention and Yield of acid Lime (*Citrus aurantifolia* Swingle). *Biological Forum—An International Journal*. 2021;13(3a):348-354.
- Zaid A, Mohammad F, Fariduddin Q. Plant growth regulators improve growth, photosynthesis, mineral nutrient and antioxidant system under cadmium stress in menthol mint (*Mentha arvensis* L.). *Physiology & Molecular Biology of Plants*. 2019;26:25-39
- Zeng H, Yang W, Lu C, Lin W, Zou M, Zhang H, Huang X. Effect of CPPU on carbohydrate and endogenous hormone levels in young macadamia fruit. *PLoS One*. 2016;11:e0158705.
- Zhang W, Corwin JA, Copeland D, Feusier J, Eshbaugh R, Chen F, Atwell S, Kliebenstein DJ. Plastic Transcriptomes Stabilize Immunity to Pathogen Diversity: The Jasmonic Acid and Salicylic Acid Networks within the *Arabidopsis/Botrytis* Pathosystem. *The Plant Cell*. 2017;29(11):2727-2752.
- Zubair M, Hussain SS, Muneeb-ul-Rehman, Baba JA. Influence of solubor, biozyme and triacontanol on leaf and fruit nutrient content of apple cv. Red Delicious. *International Journal of Agricultural Sciences*. 2018;14(1):85-91.