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Impact of new generation plant growth regulators on fruit crops – A review

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Abstract: Plant growth regulators (PGRs) are artificially synthesized substances that control growth, development, and other various physiological processes in plants. Synthesized auxins, ethylene, abscisic acid, cytokinin, and gibberellins are only a few of the key PGRs that have been studied and used for quite a long period of time. brassinosteroids, salicylic acid, jasmonic acid, CPPU (N-(2-chloro-4-pyridyl)-N'-phenylurea), putrescine, hexanal, triacontanol, melatonin, and other chemicals have been added to the list of PGRs. These PGRs can be considered the new generation of plant growth regulators. These relatively novel hormones are critical for a plant's growth and development. They aid in the increase of not only the quantity (fruit set, length, weight, yield, volume, pulp percentage, and so on) but also the quality of fruit crops (fruit colour, firmness, total soluble solids, total sugar, ascorbic acid content, etc). They also help to prolong the shelf life of certain fruits and minimize the losses after harvesting. As a result, these new-generation PGRs can be used to boost an orchard's productivity and income while minimizing pre and post-harvest losses to the greatest extent possible. Hence, this extensive review discusses the impact of these new-generation PGRs on fruit crops.

Keywords: development; growth; fruit set; shelf life; post-harvest; yield

Plant Growth Regulators (PGRs) are chemicals that regulate growth, development, and other physiological processes by upregulating or downregulating certain components. PGRs can be either natural or man-made. PGRs affect or regulates one or more physiological processes. Various PGRs have different sites and actions in different plants. PGRs are divided into two groups based on how long they have been utilized in the horticulture industry. Some PGRs have been successfully harnessed and are commonly used by farmers such as gibberellins, abscisic acid, ethylene, auxins, and cytokinins (Rademacher 2015). Apart from these, there are PGRs whose efficacy and efficiency are well established, but which have yet to be exploited at the grassroots level due to some technological gaps and a lack of proper information on their impact on fruit crops. Jasmonic acid (JA), brassinosteroids (BR), CPPU, salicylic acid (SA), and other compounds are among them (Mani et al. 2021). The structures of these PGRs are mentioned in Figure 1.

Brief overview of established knowledge. In most instances, the use of plant growth regulators (PGRs) alters the hormonal balance within treated plants. This can be accomplished through various methods, such as the application of naturally occurring hormones or their synthetic counterparts externally, inhibiting

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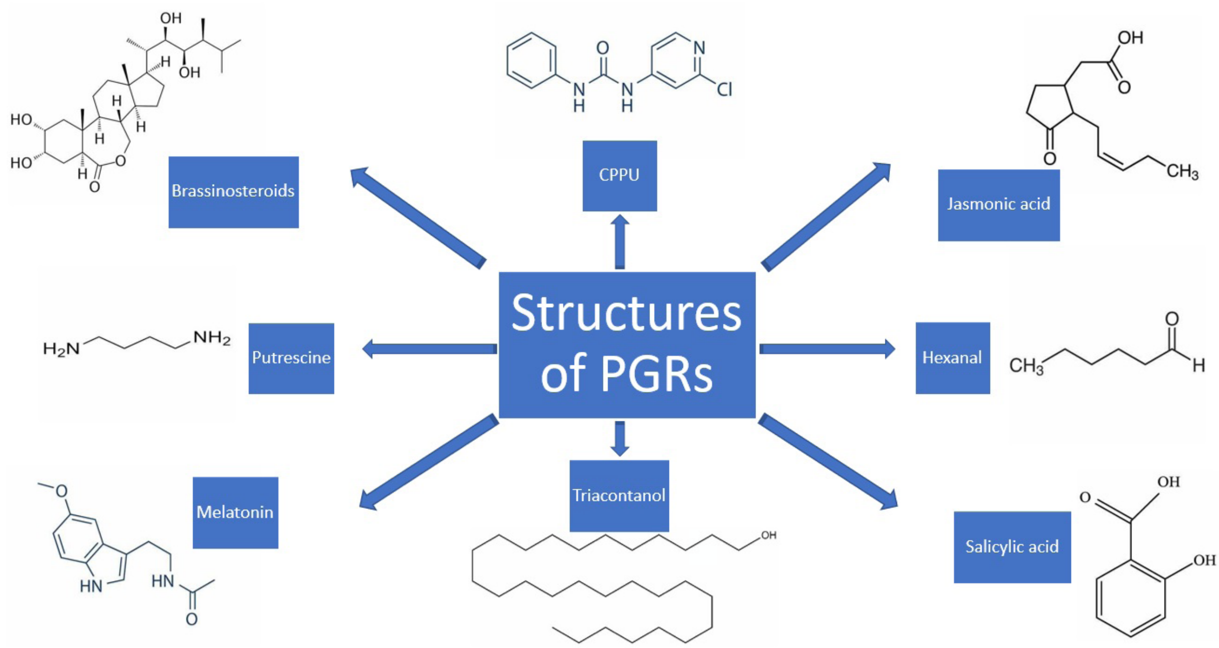

Figure 1. Chemical structures of some new generation PGRs

the production of endogenous hormones, impeding their movement from production sites to action sites, or blocking hormone receptors (Rademacher 2015). There are many ways in which a plant may respond to auxins, including downward root development in response to gravity (geotropism) the promotion of apical dominance (the propensity of an apical bud to secrete hormones that inhibit the growth of the buds on the stem below it), the growth of flowers, fruit development, and fruit set. Furthermore, the active component in the majority of rooting solutions used during vegetative propagation is auxin. Gibberellins encourage seed germination and breakdown of seed dormancy as well as cell division and elongation. The seeds of some species can be aided in germination by soaking in GA solution. Unlike other hormones, cytokinins are present in both plants and mammals (Seegobin et al. 2018). Cytokinins play a significant role in influencing multiple aspects of plant growth, development, and physiology. These include seed germination, apical dominance, flower and fruit development, leaf senescence, and interactions between plants and pathogens, among others (Akhtar et al. 2020).

They are typically included in sterile tissue culture media to encourage cell proliferation. If the medium's mixture of growth-regulating chemicals is high in cytokinins and low in auxin, the explant of tissue culture will sprout many shoots. In contrast, if the mix has a high auxin to cytokinin ratio, the explant will produce more roots. Additionally, cytokinins are used to delay aging and death (senescence). Because it only exists in a gaseous state, ethylene is special. By stimulating ripening, epinasty, and abscission of leaves, it encourages senescence. Stress causes plants to create more ethylene, and during the culmination of a plant's life, ethylene is frequently found in high concentrations within its cells. A rise in ethylene in leaf tissue is one of the reasons leaves tumble from trees during the fall. In the 1930s, a systematic application of plant growth regulators (PGRs) commenced, employing substances like ethylene and acetylene to stimulate the flowering and fruiting processes in pineapple (Bartholomew 2014). Additionally, ethylene is used to promote fruit ripening (e.g., green bananas). In general, abscisic acid (ABA) inhibits plant development. In response to water deficit, ABA closes stomata, and during seed maturation, dormancy is encouraged, which prevents seeds from developing. Additionally, it causes leaves, flowers, and fruits, to abscise.

The new generation of PGRs described in this review includes brassinosteroids, salicylic acid, jasmonic acid, triacontanol, CPPU, hexanal, putrescine, and melatonin. Brassinosteroids (BRs) application is helpful in reducing fruit abortion and fruit fall. The increment in pollen tube development and fertilization can also be regulated. Fruit abscission was avoided by BR. BRs also control the activity of defense-related enzymes, allowing for the development of effective defense mechanisms against a variety of pathogens. It has been discovered

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that modifying the level of endogenous BRs improves fruit quality (Li et al. 2010; De Bruyne et al. 2014). Jasmonic acid (JA) is an organic compound found in the jasmine flower (*Jasminum grandiflorum*). The octadecanoid pathway can biosynthesize it from linolenic acid. JA improves embryo development, flower determination and development, and overall fruit set (Hink et al. 2008). By synthesizing enzymes including proteinase inhibitors and chitinases, as well as volatile aldehydes and oxoacids, JA and methyl jasmonate (MJa) defend plants from herbivores and pests. Total antioxidants and content of various phenolic compounds can be improved by JA and MJa (Kohli et al. 2018). Salicylic acid ($C_7H_6O_3$) is a monohydroxy benzoic acid with the formula $C_7H_6O_3$ (a type of beta-hydroxy acid and phenolic acid). β-d-salicin 1metabolism produces Salicylic acid 2 (Mahdi 2014). Abiotic stress tolerance, Induced systemic resistance (ISR), Systemic acquired resistance (SAR) of plants are all influenced by salicylic acid (SA). Epicuticular waxes include triacontanol (TRIA), which is a naturally existing plant growth regulator. TRIA is used to boost crop production due to its role in improving cell division and elongation, nutrient uptake, stress tolerance, etc. (Naeem et al. 2012). Hexanal, a natural volatile chemical with antibacterial activity, has been discovered to increase the fruit's shelf life and keep its original colour (Song et al. 1996). The overall response of these PGRs on various aspects of fruit crops is illustrated in Figure 2.

This review entails the PGRs of new classes which are being found to have a strong potential for modulating plant development functions at extremely low doses. As agriculture and horticulture become more mechanized, and science expands the possibilities for pushing the boundaries of traditional crop production systems, the role of knowledge in extrinsic modulation of growth processes becomes increasingly important for effectively tapping these multipurpose resources to improve agricultural productivity and quality under dwindling agroclimatic conditions as the need for agriculture commodities is increasing day by day due to increasing population. The utilization of new generation PGRs in different fruit crops all over the world is mentioned in Table 1.

Brassinosteroids (BRs). In plants, a class of steroidal phytohormones that are polyhydroxylated with structures resembling those of steroid hormones in animals is known as brassinosteroids (BRs). Numerous physiological processes, such as plant development, defense mechanism, and growth, are also controlled by brassinosteroids. Brassinosteroids can be classified on the basis of side chains' different alkyl-substitution patterns as C_{27}, C_{28}, or C_{29}. For active BRs, a trans-fused A/B ring system with a 6-ketone or 7-oxa-6-ketone system at ring B and two hydroxyl groups at ring A is typically necessary. The chemical structure of brassinolide is ((22R, 23R, 24S)-2α, 3α, 22, 23-tetrahydroxy-24-methyl-B-homo-7-oxa-5α-cholestan-6-one) (Tang et al. 2016). The impact of BR application was found to be significant in enhancing the growth, yield, and quality of several fruit crops. For example, fruits can be treated with BRs as a foliar spray prior to harvest to preserve their quality and lengthen their shelf life. By applying an aqueous solution of BRs exogenously, grape cluster diameter and weight as well as berry length, diameter, and weight, were dramatically enhanced. By slowing the degradation rate of soluble solids and titratable acidity, BRs preserved peel colour even during cold storage (Champa et al. 2015). By applying BRs exogenously to grapes, researchers were able to reduce berry drop, increase fruit firmness, lower ethylene production rates, and respiration during storage, and decrease decay in the berry (Liu et al. 2016). Vergara et al. (2018) found that spraying BRs on grapes increased their soluble solids, colour, and anthocyanin content. According to Lisso et al. (2006), spraying grape berries with BRs significantly accelerated the ripening of the fruit. Consistent with this, Chervin et al. (2004), and Symons et al. (2006) demonstrated that exogenous application of BR-inhibitors can significantly delay or promote the berry ripening process in grapes by altering the level or concentrations of BR. According to Luan et al. (2013), BRs at 0.4 mg/L increased the overall content of anthocyanin in grapes compared to the fruits in control.

Chinese ber (*Ziziphus jujuba* cv. 'Huping') fruits that were treated with BR had much lower storage ethylene levels than untreated fruits (Zhu et al. 2010). In order to preserve higher titratable acidity and total soluble solids as well as to increase the firmness of the fruit, brassinosteroids were externally applied to the ber (Zhu et al. 2010). In fruit crops, one of the crucial physiological reactions of BRs is thought to be the facilitation of the ripening process of fruit by promoting ethylene production by regulating the expression of genes involved in the ethylene biosynthesisn by upregulating the expression of enzymes such as ACC synthase, which catalyzes the synthesis of a precursor to ethylene called 1-aminocyclopropane-1-carboxylic acid (ACC). The only way these compounds could increase fruit ripening

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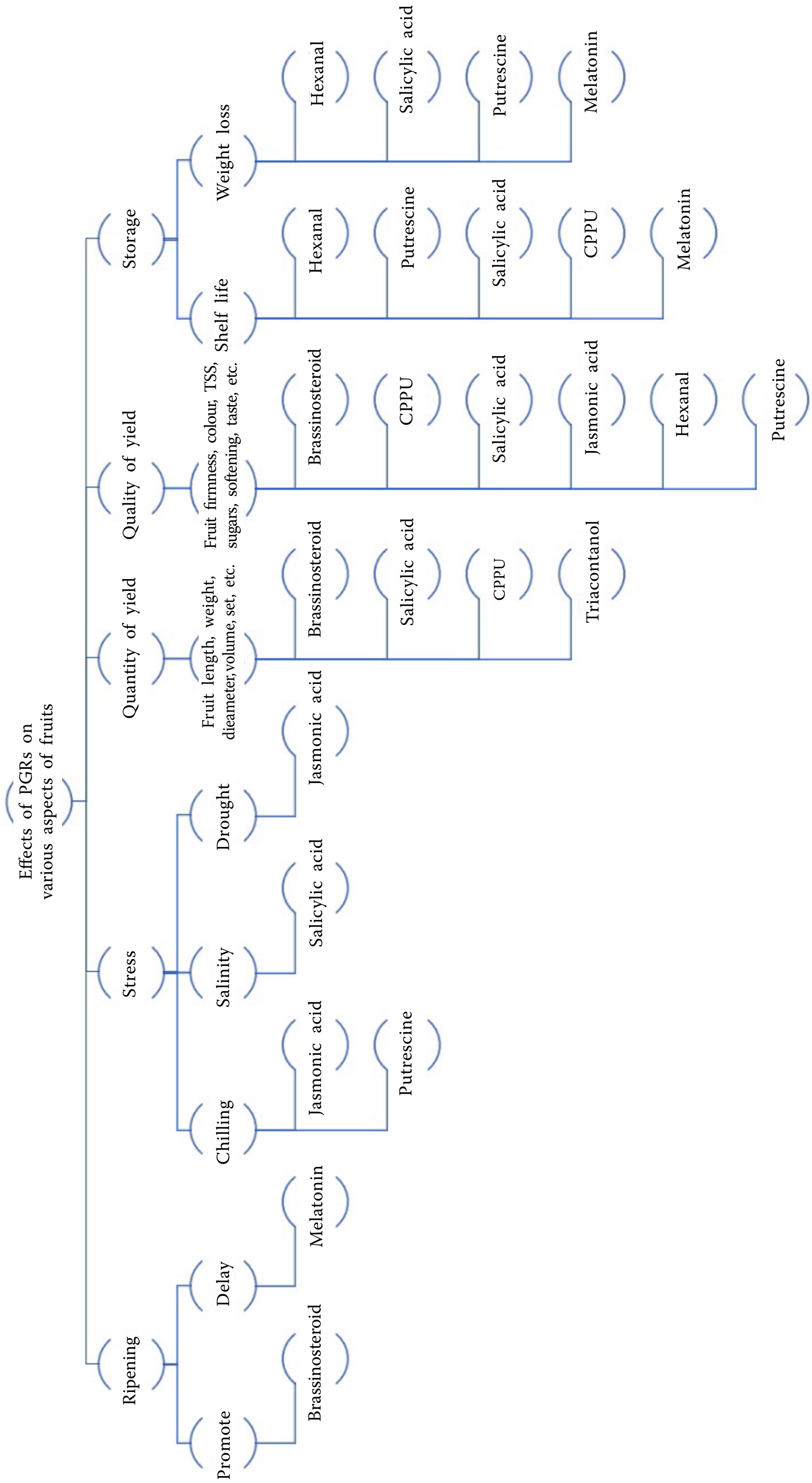

Figure 2. Overall response of new generation PGRs on various aspects of fruit crops

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Table 1. Utilization of New Generation PGRs in different fruit crops all over the world

S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
1.	Brassinosteroid	grapes	berries	spray	Enhanced ripening significantly	California, USA	Lisso et al. (2006)
			berries	spray	Promoted ripening	Healdsburg, USA	Symons et al. (2006)
			berries	spray	Improved peel colour and encouraged ripening	Healdsburg, USA	Symons et al. (2006)
			berries	spray	Increased berry peel colour and anthocyanin content	Jingyang, China	Luan et al. (2013)
			berries	spray	Enhanced cluster weight, berry weight, improved berry length, and breadth; increased berry hardness; decreased softening of the berries; stabilised anthocyanins; suppressed deterioration; increased total phenolics; decreased berry shatter	Punjab, India	Champa et al. (2015)
			berries	spray	Fruit firmness was increased, respiration and production of ethylene during storage were reduced, and berry drop and decay were minimised	Linwei, China	Liu et al. (2016)
			berries	spray	Improved colour, soluble solids, and anthocyanin levels	Santa Maria, Chile	Vergara et al. (2018)
		ber	fruits	dipping application	Reduced ethylene evolution and respiration rates, delayed fruit senescence, and delayed ripening	Shanxi, China	Zhu et al. (2010)
			fruits	dipping application	Increased fruit firmness and maintenance of elevated TSS and TA	Shanxi, China	Zhu et al. (2010)
		mango	fruits	spray	Hastened fruit ripening	Gingin and Dongara, Australia	Zaharah et al. (2012)

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S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
1.	Brassinosteroid	mango	fruits	post-harvest application	Promoted colour development and fruit softening	Gingin, Australia	Zaharah and Singh (2010)
		strawberry	leaves and fruits	spray	Helped in ripening	Huelva, Spain	Bombarely et al. (2010)
			fruits	injection	Fruit ripening	Ponta Grossa, Brazil	Ayub et al. (2018)
			fruits	spray	Encouraging cell division during the first stages of fruit formation	Beijing, China	Chai et al. (2013)
		papaya	leaves	spray	Hastened the rate of senescence	Portugues, Brazil	Gomes et al. (2013)
		sweet cherry	vegetative parts and fruits	spray	Maintained higher TA and TSS; increased fruit firmness; improved anthocyanins, peel colour, ascorbic acid, and organic acids; increased postharvest life	Kerman, Iran	Roghabadi and Pakkish (2014)
			vegetative parts and fruits	spray	Early maturation, increased development of peel colour development and fruit firmness	Fresno, Madera, Orlando, and Salem, USA	Mandava and Wang (2015)
		litchi	leaves and fruits	spray	Increased fruit firmness and decreased fruit drop	Shenzhen, China	Peng et al. (2004)
		orange	fruits	spray	Increased sugar content and fruit weight	Fujian, China	Changfang et al. (2004)
			leaves, flowers and fruits	spray	Increased fruit set	Shizuoka, Japan	Sugiyama and Kuraishi (1988)
		apple	fruits	pre-harvest application	Enhanced fruit diameter, weight, firmness, total sugars, and colour	Egypt	Attia and Adss (2021)

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S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
1.	Brassinosteroid	pear	fruit	spray	Improved TSS, ascorbic acid content, and non-reducing sugar	Uttrakhand, India	Thapliyal et al. (2016)
		passion fruit	Vegetative parts	spray	Increase in yield	Rio de Janerio, Brazil	Gomes et al. (2006)
2.	Jasmonic acid	banana	fruits	exogenous application	Increases chilling tolerance	Guangzhou, China	Zhao et al. (2013)
			fruits	exogenous application	Reduced chilling injury	Kenya	Elbagoury et al. (2020)
		peach	leaves	exogenous application	Improves drought tolerance	China	Ge et al. (2010)
			fruits	exogenous application	Increased the soluble sugar content	Weifang, China	Zhao et al. (2021)
			fruits	exogenous application	Reduced chilling injury	Hefei, China	Chen et al. (2019)
		apple	branches	spray	Increase tolerance to low temperature	Hiroshima, Japan	Yoshikawa et al. (2007)
		pomegranate	fruits	exogenous application	Reduces chilling injury	Alicante, Spain	Sayyari et al. (2011)
3.	Salicylic acid	strawberry	leaves and fruits	exogenous application	Increased fruit set and yield	Jammu & Kashmir, India	Baba et al. (2017)
			leaves and fruits	pre-harvest application	Increased content of phenolic groups (hydroxycinnamic acid, anthocyanins, flavonols, etc.)	Brdo Pri Lukovici, Slovenia	Gačnik et al. (2021)
			vegetative parts and fruits	spray	Improved vegetative growth and fruit yield	El-Beheira, Egypt	Mohamed et al. (2018)

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S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
3.	Salicylic acid	strawberry	vegetative parts and fruits	spray	Increased salinity tolerance	El-Bostan, Egypt	Roshdy et al. (2021)
			fruits	exogenous application	Decreased weight loss and increased storage life	India	Attri et al. (2015)
			vegetative parts and fruits	spray	Maintained total carotenoids, total flavonoids, total phenolics, titratable acidity, and antioxidant activity and reduced weight loss	Ashmoun, Egypt	Shaaban et al. (2020)
		guava	branches and fruits	spray	Increased fruit set and yield	Jharkhand, India	Bindhyachal et al. (2016)
			leaves	spray	Increased TSS, total sugar, and ascorbic acid content	Haryana, India	Kaushik et al. (2021)
		banana	fruits	post-harvest application	Reduced chilling injury and preserved quality during cold storage	Tehran, Iran	Khademi et al. (2019)
		grapes	fruits	spray	Increased total phenol content	Badajoz, Spain	Blanch et al. (2020)
		citrus	fruits	dipping application	Reduced decay and weight loss, and preserved TSS, acid content, and firmness	Kafr El-Sheikh, Egypt	Ennab et al. (2020)
		apple	fruits	soaked	Increased firmness, TA, peroxidase activity, and lowered TSS	Uromieh, Iran	Kazemi et al. (2011)
		pomegranate	leaves and fruits	spray	Improved yield, firmness, colour, and organic acid content	Elche, Spain	García-Pastor et al. (2020)
		peach	fruits	dipped	Reduced weight loss, increased flesh stiffness, increased SSC, higher TA levels, and higher skin brightness	Rawalpindi, Pakistan	Tareen et al. (2012)
			leaves and fruits	pre-harvest application	Increased fruit weight and yield	Davutlar, Türkiye	Erogul and Özsoydan, (2020)

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S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
4.	CPPU	pomegranate	leaves and fruits	spray	Improved TSS and total sugar content	Maharashtra, India	Supe and Marbhal (2008)
		guava	vegetative parts and fruits	spray	Improved TSS, ascorbic acid and total acid content, fruit firmness	Fekejur, Iran	Sabaghnia and Nahandi (2019)
		mango	leaves and fruits	spray	Increased fruit retention, quality, and yield	Maharashtra, India	Pujari et al. (2016)
		kiwi	fruits	dipping application	Increased fruit weight, length, and diameter	Himachal Pradesh, India	Banyal and Banyal (2020)
			fruits	dipping application	Increased fruit size and yield	Himachal Pradesh, India	Pramanick et al. (2015)
			fruits	exogenous application	Improved fruit quality and taste	Türkiye	Şen et al. (2021)
		grapes	berries	pre-harvest application	Extends storage lifetime	Bab Sharqi, Egypt	Marzouk and Kassem (2011)
5.	hexanal	guava	leaves and fruits	pre-harvest application	Reduced decay incidence, improved firmness, pectin, and phenol contents	Punjab, India	Gill et al. (2016)
			fruits	exogenous application	Improved taste, texture, colour, and appearance	Karnataka, India	Revankar et al. (2020)
			leaves and fruits	pre-harvest spray	Reduced post-harvest weight loss	India	Gill et al. (2018)
		mango	leaves and fruits	pre-harvest application	Improved storage life, TSS, total sugars, carotenoid content, and vitamin C	Tamil Nadu, India	Preethi et al. (2021)
			fruits	pre-harvest application	Enhances fruit retention and shelf life	Tamil Nadu, India	Anusuya et al. (2016)

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S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
5.	Hexanal	mango	fruits	post-harvest application	Increased shelf life	Chennai, India	Jan et al. (2022)
		apple	fruits	exogenous application	Increased TSS and decreased physiological weight loss	Leuven, Belgium	DeBrouwer et al. (2020)
		peach	fruits	post-harvest application	Extended the fruits' shelf life	Vineland, Canada	Ranjan et al. (2020)
		sweet cherry	leaves and fruits	pre- and post-harvest application	Improved color, firmness, anthocyanins, and phenolics	Ontario, Canada	Sharma et al. (2010)
6.	Triacontanol	strawberry	leaves and fruits	spray	Increased fruit set	Jammu & Kashmir, India	Baba et al. (2017)
			leaves and fruits	spray	Increased fruit yield, ascorbic acid, total sugars, and anthocyanin content	Kharora, Punjab	Sood et al. (2018)
			leaves	spray	Increased fruit yield	Uttar Pradesh, India	Rakesh et al. (2012)
			vegetative parts	spray	Increase in size and weight of fruit	Uttar Pradesh, India	Khunte et al. (2014)
			leaves and fruits	spray	Promoted fruit development	Nanjing, China	Pang et al. (2020)
		guava	leaves and fruits	spray	Increase in the yield	India	Singh (2013)
			leaves and fruits	spray	Increased fruit yield	Punjab, India	Jain and Dashora (2010)
		citrus	leaves and fruits	spray	Increased fruit retention and early harvest	Rajasthan, India	Choudhary et al. (2013)
		apple	leaves and fruits	spray	Improved fruit set and yield	Uttar Pradesh, India	Zubair et al. (2018)
		mango	leaves and fruits	spray	Improved fruit retention	Maharashtra, India	Patil et al. (2005)
		pomegranate	leaves	spray	Increased fruit length and diameter	Himachal Pradesh, India	Aziz et al. (2013)

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S. No.	PGR used	Crop	Parts of crop	Types of treatment	Effect on any attributes	Region of the experiment conducted	Reference
7.	Putrescine	pear	leaves and fruits	spray	Lengthen the storage life and maintain the quality	Punjab, India	Singh et al. (2019)
			leaves and fruits	spray	Reduced weight loss and increased sensory quality, starch content, and titrable acidity	Punjab, India	Singh et al. (2019)
		peach	vegetative parts and fruits	spray	Reduced chilling injury index, preserves fruit quality, and extends the storage life	Attock, Pakistan	Abbasi et al. (2019)
		citrus	fruits	dipping application	Reduced decay and weight loss, and preserved TSS, acid content, and firmness	Kafr El-Sheikh, Egypt	Ennab et al. (2020)
8.	Melatonin	plum	fruits	exogenous application	Extended storage life and delayed fruit ripening	Shengzhou, China	Yan et al. (2022)
		mango	fruits	exogenous application	Delayed ripening	Minab, Iran	Rastegar et al. (2020)
		banana	fruits	exogenous application	Delay in the ripening process	Chengmai, China	Hu et al. (2017)
		peach	fruits	exogenous application	Decreased the decay incidence, delay senescence and weight loss	Xi'an, China	Gao et al. (2016)
		cherry	fruits	exogenous application	Fruit ripening was delayed	Lleida, Spain	Tijero et al. (2019)
			leaves and fruits	spray	Improved fruit weight, colour, firmness, and TSS	Murcia, Spain	Carrión-Antoli et al. (2021)
		pomegranate	fruits	exogenous application	Increased anthocyanins content and improved colour	Iran	Aghdam et al. (2020)
			vegetative parts and fruits	pre-harvest application	Improved fruit quality	Alicante, Spain	Lorente-Mento et al. (2021)
		pear	fruits	pre-harvest application	Improved colour and anthocyanin content	Shenyang, China	Sun et al. (2021)

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was through the exogenous application; however, any change in the endogenous level of BRs had little to no noticeable effects on climacteric fruit ripening like mango (Zaharah et al. 2012).

Epibrassinolide (Epi-BL) which is a derivative of BR, postharvest application, according to Zaharah and Singh (2010), not only accelerated the ripening of mango fruit by influencing the climacteric peak but also improved the quality of fruit by promoting colour development and fruit softening. They came to the conclusion that the rise in peel coloration of mango fruits treated with Epi-BL may have been caused by the action of enzymes that break down chlorophyll or possibly by the buildup of carotenoids. Furthermore, the strawberry fruits' ripening was enhanced by the exterior BRs spray (Bombarely et al. 2010). Chai et al. (2013) studied whether BRs might have been engaged in the major phases of fruit development by increasing strawberry fruit cell division and expedite ripening. It was strengthened by suppressing the BRs receptors' expression. Chai et al. (2013) discovered that the expression of the BR receptor FaBRI-1 dramatically increased swiftly from the strawberry fruit's early red to white phases of development, demonstrating the link between BRs and fruit ripening. According to research conducted by Ayub et al. (2018) on the influence of Epi-BL on the FaBRI1 receptor's expression and the signaling pathway in Camino Real strawberries, perception pathways and signal transduction show very little gene activity. This finding raises the possibility that BR, but only at very low doses, may be important for strawberry fruit ripening. Moreover, according to Gomes et al. (2013), BR analogs caused stressed papaya plants to redistribute photoassimilates and other chemicals toward the younger leaves, hastening the pace of ageing in older leaves. Fruit peel colour was also improved by foliar applications of BRs by boosting anthocyanin, phenol content, organic acid, and ascorbic acid (Roghabadi, Pakkish 2014). In addition, Roghabadi and Pakkish (2014) hypothesized that BRs might be essential in reducing the damage due to oxidation brought on by cold stress and enhancing the ability of sweet cherries kept at 1 °C to survive cold. Sweet cherry cultivars 'Tulare' and 'Bing' had early maturation as a result of the exogenous administration of HBR, a form of BRs, which boosted peel colour development, fruit firmness, and the amount of force needed to extract fruits from the stem (Mandava, Wang 2015). BL increased the amounts of pectin which is soluble in water and protopectin and also the activity of some fruit-softening enzymes like polygalacturonase (PG) as well as pectin methylesterase (PME). It also enhanced the amount of calcium in the fruit pericarp, greatly decreased fruit cracking, increased fruit firmness, and decreased fruit drop in litchi (Peng et al. 2004). According to Sugiyama and Kuraishi (1988), BRs applied to orange trees around flowering and once again after 25 days considerably boosted fruit yield, lowered leaf and fruit drop, and preserved the internal quality of the fruit.

According to Changfang et al. (2004), BR considerably boosted the weight of orange fruits compared to those that weren't treated by enhancing fruit cell division. The yellow passion fruit's predicted output increased by 65 percent as a result of the administration of BR analog (BR-3) (Gomes et al. 2006). Brassinosteroids' sprayed on pear improved TSS (total solube solids), ascorbic acid content, and non-reducing sugar (Thapliyal et al. 2016). According to Attia and Adss (2021), pre-harvest application of BRs led to enhanced fruit diameter, weight, firmness, total sugars, and colour in apples.

Jasmonic acid. Jasmonic acid (JA), an endogenous substance that regulates growth, was initially identified within higher plants as a stress hormone. Derivatives of fatty acids known as jasmonates (JAs) include, among others, JA, jasmonate isoleucine conjugate (JA-Ile), and methyl jasmonate (MeJA). The core component of the JA chemical structure is 3-oxo-2'-cis-pentenyl-cyclopentane-1-acetic acid, a signaling molecule that is endogenous in nature, implicated in a number of developmental events, and formerly assumed to be a hormone related to stress in higher plants (Wang et al. 2020). Initially, it was believed that JA was a stress hormone connected to biotic stress responses in plants, granting immunity to hemibiotrophic and biotrophic pathogens, as opposed to salicylic acid (SA), which affects how plants react to necrotrophic infections. Plant reactions to abiotic stress are also linked to JA (like wounding, soil salinity, and UV). Furthermore, several scientists have discovered that Jasmonic acid regulates a range of physiological functions, including root growth, reproductive organ growth, and plant senescence. JA also plays a part in the synthesis of many metabolites like phytoalexins and terpenoids (Ghorbel et al. 2021). JAs, ABA, and polyamines were shown to be connected to stress responses in apples due to low temperature (Yoshikawa et al.

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2007). The exogenous doses of MeJA to bananas under cold storage quickly activate two MYC2 TFs, according to recent research (Zhao et al. 2013). Furthermore, Zhao et al. (2013) found that MeJA greatly enhances the expression of the genes that stimulate CBF (C-repeat Binding Factor) expression (ICE-CBF, Inducer of CBF expression), a pathway gene that responds to cold. These results demonstrate that chilling endurance induced by MeJA in banana fruit is mediated by the transcription factor MaMYC2, working in concert with MaICE1. Exogenous treatment of JAs, on the other hand, could help *P. armeniaca* to recover from drought stress. Transient Jasmonic acid buildup could accelerate leaf senescence, improve plant endurance to low temperatures, and avoid extreme water loss in a drought-tolerant *P. armeniaca* genotype as JAacts as a signalling molecule that can trigger stomatal closure in response to various stress factors, including water deficit, according to Ge et al. (2010). After the exogenous application in peaches, the content of soluble sugar was 10% more in the jasmonic acid-treated fruits (Zhao et al. 2021). In the course of peach fruit storage, chilling injury's negative effects were lessened when JA was applied (Chen et al. 2019). When calcium chloride and JA were applied to bananas, chilling damage during storage in cold was reduced (Elbagoury et al. 2020).

Salicylic acid. Salicylic acid (SA) and its derivatives, which are endogenous plant hormones, are phenolic acids that have a ring attached to the hydroxyl and carboxyl groups. Cinnamic acid serves as the precursor to salicylic acid. It is mostly produced inside the plant, in the cytoplasm of cells. SA is chemically ortha hydroxyl benzoic acid, and has the formula $C_7H_6O_3$ (Hassoon, Abduljabbar 2019). Salicylic acid has crucial physiological functions in the growth and development of plants, such as enhancing the plant's response to biotic and abiotic stresses, boosting system acquired resistance (SAR) enhancing or altering endogenous signaling inside the plant to tolerate a variety of pressures. The plant can withstand environmental stresses such as heavy metal stress, coldness, heat, dryness, ammonia stress, and salt stress, especially the harmful sodium chloride compound because of its ability to act as a versatile signaling molecule that transmits information within plant cells and between different plant tissues. Its ability to stimulate and transmit cellular responses is central to its functions in plant defense, growth, development, and stress tolerance (Simaei et al. 2012; Hassoon, Abduljabbar 2019;). Baba (2017), depicted that Salicylic acid @ 2 mM produces the highest number of flowers per plant, fruit set, the number of fruits per plant, and fruit yield in strawberry plants. Foliar spray of salicylic acid on strawberry fruitsbefore harvest increased the content of phenolic compounds such as hydroxycinnamic acid, anthocyanins, flavonols, etc. (Gačnik et al. 2021). Mohamed et al. 2018, observed in the treated strawberry cultivars, a 3 mM salicylic acid foliar spray dramatically improved vegetative growth, the number of bloom clusters, and earliness. SA has been shown to promote pollen germination, pollen tube growth, and pollen viability, leading to improved fertilization rates. By facilitating successful pollination and fertilization, SA can contribute to increased fruit set and by minimizing stress-related limitations, SA indirectly supports fruit set. A higher crop yield (number of harvested fruit per tree and kg per tree) and quality parameters (organic acids, aril colour, firmness, and individual sugars), as well as more concentration of ascorbic acid, anthocyanins, and phenolics, were observed in pomegranate treated trees with 10 mM MeSA (García-Pastor et al. 2020).

A finding suggested the application of 90 ppm SA foliar application lessens the negative effects of salinity in cv. 'Camarosa' of the strawberry plant (Roshdy et al. 2021).

Attri et al. (2015), investigated the impact of SA on plum postharvest life. Salicylic acid-treated fruits had the lowest weight loss of 14.97 percent after 20 days of storage and had a longer shelf life than untreated fruits. SA application on plum helped in softening, maintaining titratable acidity, reducing weight loss, maintaining total flavonoids, total carotenoids, antioxidant activity, and total phenolics (Shaaban et al. 2020). In the guava variety Arka Amulya, the highest fruit yield (12.30 kg) was observed in Salicylic acid 100 ppm treatment which was statistically comparable to NAA 20 ppm (Bindhyachal et al. 2016). A combination of salicylic acid with other chemicals was also found to have a synergistic effect on quality. Guava exhibited significant TSS, ascorbic acid, and total sugar as a result of the action of $CaCl_2$ (2 percent) + SA (2 mM) together which had a more potent combination impact (Kaushik et al. 2021). According to Blanch et al. (2020), with 100 ppm (parts per million)of salicylic acid application, the total phenol content and free radical scavenging activity increased in grapes. Ennab et al. (2020), studied the combination of salicylic acid and putrescine and observed

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that weight loss and decay were significantly reduced. Both materials preserved ascorbic acid, total soluble solids (TSS), fruit firmness, acidity, and TSS : acid ratio well throughout storage. Compared to apple fruits treated with the control solution, those treated with SA solution for 5 minutes showed lower TSS, and increased levels of peroxidase activity, firmness, superoxide dismutase activity, and TA (Kazemi et al. 2011). SA application at 2.0 mmol/L concentration showed considerably reduced loss in weight, higher TA levels, increased flesh stiffness, higher skin brightness, and increased SSC in peach (Tareen et al. 2012).

Chloro-4-pyridyl)-N'-phenylurea(CPPU). Forchlorfenuron, also known as N-(2-Chloro-4-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. The use of 1-MCP, to block ethylene response, helped preserve the overall quality of the fruits (Şen et al. 2021).

Hexanal. Hexanal is an alkyl aldehyde that's also called hexanaldehyde or caproaldehyde. Hexanal, a natural volatile molecule with antibacterial activity, has been found to increase fruit longivity and keep their original colour (Song et al. 1996). Hexanal, is used to create fruity flavours. While hexanal smells like freshly cut grass, similar to cis-3-hexenal, it alters fruit metabolism to create fruity flavours. It might be helpful as a natural extract that stops the fruit from rotting. The enzyme phospholipase D (PLD) causes the fruit to shrink and rot, eventually causing the membrane to collapse. Hexanal works by lowering and slowing the development of PLD, which slows the fruit's membrane breakdown (Subramanian, Finnis 2019). Pre-harvest application of hexanal in guava led to a reduction in decay incidence and improvement in firmness, pectin, and phenol contents (Gill et al. 2016). Exogenous application of hexanal on guava fruits improved taste, texture, colour, and appearance (Revankar et al. 2020). Preethi et al. (2021) found that the pre-harvest spray of hexanal on mango improved storage life, TSS, carotenoid content, vitamin C, and total sugars. Pre-harvest spray of hexanal on mango enhanced in fruit retention and shelf life (Anusuya et al. 2016). In mango, the post-harvest spraying of hexanal increased the shelf life of the fruit (Jan et al. 2022). DeBrouwer et al. (2020) used an exogenous application of hexanal to increase TSS and decrease physiological weight loss in apples. In sweet cherry, the application of hexanal during pre as well as post-harvest led to improved colour, firmness, anthocyanins, and phenolics in the fruit (Sharma et al. 2010). A delay in the peach fruit's ability to deteriorate was seen with the post-harvest application of hexanal (Ranjan et al. 2020).

Triacontanol. The fatty alcohol 1-triacontanol, often referred to as myricyl or melissyl alcohol, has the generic chemical formula $C_{30}H_{62}O$. Ries et al. (1977) made the initial discovery of triacontanol's (TRIA) ability to regulate plant development in alfalfa (*Medicago sativa* L.). TRIA cannot be categorized as a phytohormone because it is a secondary plant growth agent, unlike primary plant nutrients (such as nitrogen, phosphorus, and potassium), which are essential for basic plant functions, secondary plant growth agents play more specialized roles in specific physiological processes. Ex-

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ogenous treatment helps in promoting growth and development: triacontanol has been found to stimulate various physiological processes in plants, including cell division, elongation, and differentiation. It can enhance overall plant growth, increase shoot and root biomass, and improve crop yield, enhancing photosynthesis: triacontanol has been shown to enhance the efficiency of photosynthesis, leading to increased assimilation of carbon dioxide and greater production of carbohydrates. This can result in improved plant vigor and better utilization of available light energy, improving stress tolerance: 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). In strawberries, spray of triacontanol led to an increase in the overall fruit set (Baba et al. 2017). The effects of triacontanol (1.25, 2.50, and 5 ppm) on the quality of strawberry cv. were investigated by Rakesh et al. (2012) on the 'Sweet Charlie' cultivar of strawberry, and plants treated with triacontanol produced the best yield. Triacontanol (100, 150, and 200 ppm) foliar spray was investigated by Khunte et al. (2014) for its impact on strawberry cv. Chandler, and the application of 100 ppm triacontanol resulted in the largest and heaviest fruits. The spray of triacontanol on guava increased the fruit yield (Singh 2013). Triacontanol's impact on the fruit production and quality of the sardar variety of guava (*Psidium guajava* L.) was examined by Jain and Dashora in 2010. They revealed that the biggest quantity of fruits was recorded in fruits sprayed with triacontanol. *Citrus reticulata* Blanco, the Nagpur mandarin, was studied by Choudhary et al. (2013) to determine how triacontanol (5, 10, 15, and 20 ppm) affected growth and yield. They discovered that the plants treated with triacontanol had increased fruit retention and an earlier harvest than the control plants. Zubair et al. (2018) showed that the best ways to increase the fruit set and production of apple fruits were to combine solubor which is a soluble boron fertilizer which plays a crucial role in pollen developement, and triacontanol, their combination showed the good effect. By Patil et al. (2005), triacontanol (300, 500, and 700 ppm) was sprayed on mangoes when they were between the size of a pea and a marble and in the blossoming stage. Triacontanol spraying produced the highest percentage of fruit retention. Aziz et al. (2013) investigated the impact of triacontanol on fruit cracking as well as quality characteristics of pomegranate and found that plants treated with triacontanol had the highest fruit length and diameter compared to control plants. Sood et al. (2018) found that fruit yield, ascorbic acid, total sugars, and anthocyanin content of strawberries were increased with the spray of triacontanol. According to Pang et al. (2020), fruit growth could be accelerated by up to 50% after triacontanol treatment (50 μM), regulating strawberry growth and development variables associated with fruit ripening.

Putrescine. Putrescine is a colourless solid that melts at temperatures close to room temperature. It is an organic molecule with the chemical formula $(CH_2)_4(NH_2)_2$. It is classified as a diamine. Polyamines (PA, including putrescine) are multifunctional plant growth regulators that participate in numerous plant growth and development processes, including DNA replication and division of cells (Galston, Sawhney 1988). PAs are mostly found in their free form in higher plants. The primary PAs in plants are spermine (Spm), spermidine (Spd), and putrescine (Put). This review pertains to the PA known as putrescine. Put which participate in a variety of physiological processes (Xu et al. 2014; Mustafavi et al. 2018), including fruit development, maturation, and senescence (Xu 2015). They also play a role in biotic and abiotic stress responses

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(Vuosku et al. 2012; De Oliveira et al. 2016; Reis et al. 2016; Mustafavi et al. 2018). Additionally, Put play a part in how plants react to stress in a range of harsh environmental situations, such as drought. These reactions may be a result of their capacity for scavenging free radicals (Farooq et al. 2009) and controlling osmosis (Aziz et al. 1999). In pear, Singh et al. (2019) found that the spray of putrescine led to the lengthening of storage life and maintenance of fruit quality. In pear fruit, putrescine spray reduced weight loss and a increased sensory quality, starch content, and titrable acidity (Singh et al. 2019). According to Abbasi et al. (2019), the use of putrescine exogenously on peach fruit reduced the chilling injury index, preserved quality, and extended the storage life of fruit. In citrus, reduction in decay, as well as weight loss and preservation of acid content, firmness, and TSS, was found with the dipping application of putrescine (Ennab et al. 2020).

However, polyamines have been implicated in the promotion stage of carcinogenesis. In certain cancers, increased levels of polyamines have been observed, and they have been associated with uncontrolled cell growth and proliferation. Polyamines are involved in the regulation of cell cycle progression, and their dysregulation can contribute to abnormal cell division and tumor growth. Polyamines can be found in elevated levels within tumor cells, tissues, urine, and/or serum of individuals diagnosed with cancer (Asai et al. 2018; Sari et al. 2021). Hence, it is recommended to use polyamines in fruit crops at concentrations that are considered safe and unlikely to induce cancer.

Melatonin. The indolic substance melatonin (N-acetyl-5-methoxy-tryptamine) is recognized in mammals as a neurohormone, antioxidant, and signaling molecule (Dubbels et al. 1995). It is synthesized from serotonin (5-hydroxytryptamine). Both the biogenic amines are produced from the amino acid tryptophan in plants and animals, through distinct biosynthetic pathways (Arnao 2014). Melatonin regulates growth, roots, and senescence in plants. Melatonin is also involved in the anti-stress response of plants. Melatonin is a direct antioxidant that causes plants to produce an antioxidative response due to its unique chemical structure, which allows it to readily interact with and neutralize free radicals. Melatonin is a plant hormone that can be utilized to improve and protect crops (Arnao and Hernandez-Ruiz 2014). Nawaz et al. (2016) found that melatonin has a diverse range of new functions in plants, such as prolonging the quality and shelf-life of fruits, as well as vegetables and aiding in vascular reconnection after grafting, and nutrient uptake from roots by modifying root architecture. Melatonin-rich food crop production (vegetables, fruits, and cereals) using a pairing of conventional and modern breeding techniques to enhance plant resistance to different abiotic and biotic stresses could also be a crucial factor in addressing food security concerns. This would increase crop yields and boost the nutritional value of products while also addressing food security concerns. Melatonin was found to have nearly double the antioxidant activity of other indoles, such as tryptophan, indole-3-methanol, indolyl-3-acetic acid, indole-3-propionic acid, and indole-3-butyric acid, and double that of ascorbic acid or Trolox. The superior antioxidant activity of melatonin is believed to be due to its unique chemical structure, which allows it to readily interact with and neutralize free radicals. Additionally, melatonin can stimulate the activity of various antioxidant enzymes within cells, further enhancing its protective effects against oxidative stress. (Cano et al. 2003). The storage life was prolonged by melatonin application exogenously and delayed fruit ripening in plums (Yan et al. 2022). According to Rastegar et al. (2020), the ripening of mango fruit was delayed by the exogenous application of melatonin. A delay in the ripening process of bananas was seen by applying melatonin (Hu et al. 2017). According to Gao et al. (2016), the incidence of degradation and loss of weight in peach fruit at the time of storage was decreased by melatonin. Tijero et al. (2019), reported that use of melatonin, delayed ripening of cherry fruit. Melatonin treatments improved harvest quality characteristics such as the weight of fruit (9–13%), firmness, titratable acidity (10–20%), colour, and total soluble solids (5–15%) (Carrión-Antoli et al. 2021). In pomegranate, the exogenous use of melatonin resulted in enhanced anthocyanins content and improved colour (Aghdam et al. 2020). The 0.1 mM dose of melatonin produced the best results, which were substantial effects on pomegranate fruit performance measures and concentration in bioactive components with antioxidant characteristics at harvest and throughout postharvest storage at 10 °C. (Lorente-Mento et al. 2021). Melatonin administration

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significantly influenced colour development and increased the levels of anthocyanins while lowering the levels of hydroxycinnamate and flavanols (Sun et al. 2021).

CONCLUSION

The goal of this review was to provide an update on findings for the regulatory effects of relatively new plant growth regulators. In numerous aspects, these endogenous PGRs are needed for the development and growth of plants. These PGRs can be utilized to improve the quality of fruits, such as colour, firmness, TSS, the content of ascorbic acid, total sugars, and so on, as well as to increase fruit length, weight, yield, and fruit sets. Additionally, these PGRs support the longevity of fruits and reduce post-harvest losses. They are also useful in providing resistance to abiotic elements like salt stress, drought stress, etc. As a result, it may be argued that this new generation of PGRs have the potential to be employed to raise an fruit and vegetable production, resulting in a higher total income.

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