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# Scientific Study of Brassinosteroids on Production of Fruit Crops: A Review

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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***Review Article***

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## ABSTRACT

Brassinosteroids (BRs) are considered as the sixth group of plant growth regulators with significant growth promoting activity in many horticulture and agriculture crops. This phytohormone was discovered from the pollen of *Brassica napus* L. on the basis of their ability to promote growth. Currently, more than 70 BRs have been isolated from different plant species, but only three viz., Brassinolide (BL), 24-Epibrassinolide (EBL) and 28-Homobrassinolide (HBL) are found to be the most biologically active forms and extensively used in various crops. They are eco-friendly, effective at very low concentration, cost effective and almost always have synergetic effect when interacts with other phytohormones. Owing to diverse physiological roles and cross talk with other hormones influence on plant growth and development, they are being collectively referred as 'pleiotropic phytohormone'. Although, BRs were discovered towards the end of twentieth century, but the dynamic applications and outcomes were reported mainly during the inception of twenty first

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century, hence BRs were termed as 'hormone of the twenty-first century'. The application of BRs at different growth stages have been reported to positively influences such as nutrients uptakes, growth, yield and quality attributes on many fruit crops which includes tropical, sub-tropical and temperate fruit crops at very low concentrations have great roles in terms of growth, yield, fruit quality and stress tolerance mechanisms, which results to lucrative adventure of farming community. This review article will provide an elucidated insight into the application of BR in different fruit crops.

*Keywords: Brassinosteroids; brassinolide; 24-epibrassinolide; 28-homobrassinolide; phytohormones; application; growth; yield.*

## 1. INTRODUCTION

Several well-established strategies are there to enhance the quality and productivity of different fruit crops for various geographical locations such as selection of varieties [37,23,81], training, pruning [35, 79], crop specific nutrient recommendation [71,72] etc. Among them exogenous application of various phytohormones have been found to be very effective. Recently, BRs application have been found to have practical implications in increasing the production of many fruit crops [97]. Brassinosteroids (BRs) are considered as the sixth group of plant growth regulators with significant growth promoting activity. This phytohormone was discovered from the pollen of *Brassica napus* L. on the basis of their ability to promote growth, Mitchell and co-workers identified a steroidal substance in the year 1970 and called it as 'brassins'. Later, it was chemically extracted by Grove et al. [33] from bee-collected pollen of rapeseed plant (*Brassica napus* L.) which was named as 'brassinolide'. However, they could extract only 10 mg of a solid crystalline form of brassinolide (BL) from 230 kg of pollen grains.

The presence of brassinosteroids was reported both in lower and higher plants, especially in angiosperms, and in all plant organs with the highest BRs concentration in pollen and immature seeds of different plants. Currently, they are known to exist in 79 different plant species, including 24 algae, one bryophyte, one pteridophyte, and 53 angiosperms [15,13,87,86]. As of now, more than 70 BRs have been isolated from different plant species, out of which, only three viz., brassinolide (BL), 24-epibrassinolide (EBL) and 28-homobrassinolide (24-HBL) were found to be most biologically active. These are biosafe and eco-friendly phytohormones, which can be used in crop plants to improve growth, yield and fruit quality [42], and they have been also reported several times to exhibit synergistic effect [73,4,52,18,63] and sometimes antagonistic cross-talks [16] with other phytohormones. Extensive studies on these chemicals' functions in plant growth and development have been carried out recently. Physiological processes, including from germination to senescence such as vascular tissue differentiation, floral reproduction, and even responses to abiotic and biotic stress [49,78,82,96,92,98,101,111,14]. BRs separation, detection, and characterisation from composite plant materials have been accomplished by the use of a variety of analytical techniques, including bioassay-based approaches, Gas Chromatography–Mass Spectrometry (GC-MS), Liquid Chromatography-Mass Spectrometry (LC-MS), Ultra-Performance Liquid Chromatography-Mass Spectrometry (UPLC-MS), and High-Performance Liquid Chromatography (HPLC) [48].

The transcript expression of genes involved in auxin biosynthesis, transport, positive signal transduction, and gibberellin biosynthesis got elevated in response to exogenous brassinosteroid treatment. As auxin, gibberellin, and brassinosteroid-related genes all responded quickly to brassinazole and brassinosteroid treatments, suggested that BR and IAA or GA were cross-talking [112]. Owing to multiple and diverse physiological roles BRs are being collectively referred to as 'pleiotropic phytohormones' [12]. Even though, BRs were discovered towards the end of twentieth century, however, the dynamic applications and outcomes were reported mainly during the inception of twenty first century, hence BRs were termed as 'hormone of the twenty-first century'. The objective this review is to insight on roles and potential applications of BRs on fruit crops for improving the growth, yield, quality, and tolerance to stresses.

## 2. CHEMICAL NATURE OF BRASSINOSTEROIDS (BRS)

Naturally occurring BRs are polyhydroxylated steroidal hormones, which have common 5αcholestane skeleton. Based on the alkyl-substitutions in the side chain, BRs have been classified as C-27, C-28 and C-29 compounds and oxygen at C-6 and hydroxyl group on the side chain at C-22 and C-23 positions which are essential for activity of BRs [12]. The basic structure of C-27-BRs is 5α-cholestane skeleton, C-28-BRs is 5α-ergostane, and C-29-BRs is 5α-stimastane and differences in the structure of these hormones are due to the type and orientation of oxygenated functions in the A- and B-ring, as well as the number and position of functional groups in the side chain of the molecule. These modifications arise during oxidation and reduction reactions. Based on the cholesterol (CR) side chain, BRs are divided by different substituents into C-23, C-24, C-25, 23-oxo, 24S-methyl, 24R-methyl, 24-methylene, 24S-ethyl, 24-ethylidene, 24-methylene-25-methyl, 24-methyl-25-methyl; without substituent at C-23, without substituent at C-24 and without substituents at C-23, C-24. BRs can also conjugate with glucose and fatty acids [115].

Several BRs have been extracted from a large number of plant species, as these steroidal chemicals are very ubiquitous in distribution throughout the plant taxa, including fruit crop species. These growth-inducing steroidal hormones were isolated from different plant parts such as stem, leaf, root, flower, anthers, pollen grains and seed. In addition, BRs have also been extracted from crown galls of chestnut plant. The highest BR-concentrations were measured in pollen and immature seeds [12].

## 3. BIOSYNTHESIS PATHWAY OF BRASSINOSTEROID

The brassinolide biosynthesised by campesterol is changed to campestanol, which is again metabolized to castasterone via bifurcation of the early or late C6 oxidation pathway and many intermediate compounds are produced before castasterone with the assistance of enzymes such as Deetiolated2 (det2), DWARF4 (dwf4) and Carboxypeptidase D (cpd).

The early C-6 oxidation pathways undergoes C-6 oxidation ahead of C-22 oxidation and late C-6 oxidation pathway hydroxylates C-22 ahead of C-6 oxidation. The late C-6 oxidation pathway plays a prominent role during photomorphogenesis, whereas the parallel early C-6 oxidation dominates during skotomorphogenesis [12].

## 4. SIGNALLING PATHWAY IN THE PRESENCE AND ABSENCE OF BRS [51]

In the presence of brassinosteroids, the binding of BR to the BRI1 receptor and its co-receptor, BAK1, resulted in the dissociation of BKI1 from BRI1 and enhanced trans-phosphorylation of BRI1 to BAK1. These events lead to full activation of the BRI1-BAK1 receptor complex, which transfers the signal through phosphorylation to BSK1 and CDG1. Once activated, BSK1 or CDG1 promote the activation of the BSU1 phosphatase, which mediates

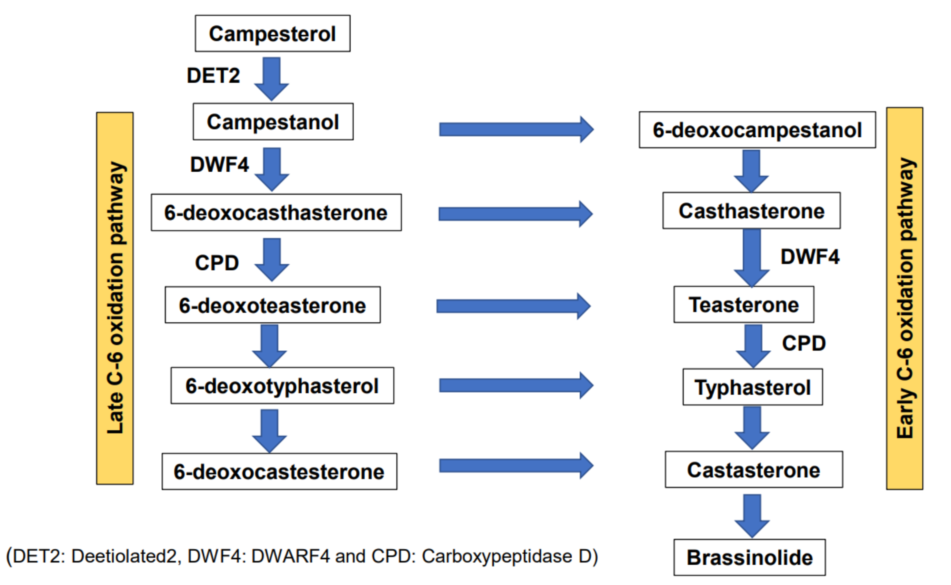


**Fig. 1. Biosynthesis pathway of brassinosteroid in plant**

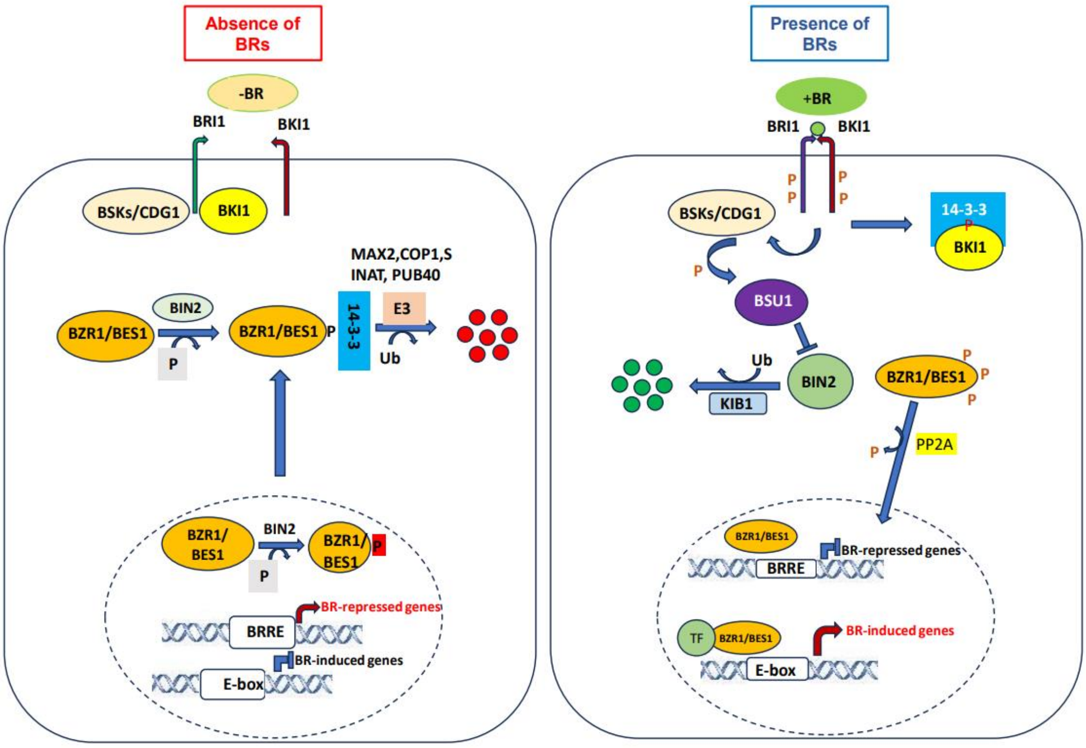


**Fig. 2. Signalling pathway in the presence and absence of BRs in plants**

*BRI1: BR Insensitive 1; BAK1: BRI1 Associated Receptor Kinase 1; BKI1: BRI1 Kinase Inhibitor1; BSK1: BR Signaling Kinase 1; CDG1: Constitutive Differential Growth 1; BSU1: BRI1 Suppressor 1; BIN2: BR Insensitive 2; BZR1/2: Brassinozole Resistant ½; PP2A: Protein Phosphatase 2A*

the dephosphorylation and inactivation of BIN2. The degradation of BIN2 will be mediated by the E3 ligase KIB1. In the meantime, activation of BZR1 and BES1 occurs with the help of PP2A by dephosphorylation, which allows the entry of certain transcription factors into the nucleus that can bind to the DNA (BRs response genes). BRs participate in diverse activities of plant growth and development. Plants which lack BRs biosynthesis and/or have a malfunction in the BR signal transduction pathway, exhibits numerous abnormal developmental phenotypes. So, this marks the significance of BR biosynthesis and their signal transduction pathway in controlling various biological processes in plants [104]. Hence, with the help of various biotechnological approaches like genetical, molecular and genomic studies, several components involved in BRs signalling pathway have been identified. A number of physiological phenomena in plants including cell elongation, root development, anther and pollen development, stem elongation, vascular differentiation *etc*. are influenced by the presence of BRs. During the absence of BR, the phosphorylated BZR1/2 are retained in the cytoplasm by 14-3-3 protein and inactivates their DNA binding activity [93].

## 5. BRS AND PHYSIOLOGICAL PROCESSES

### 5.1 Photosynthesis

a) Alleviates the effect of photoinhibition by significantly enhancing the photochemical efficiency of photosystem II (PSII) [3].
b) Significantly increases the photosynthetic activity of many plants under stress which include drought, high or low temperature, salinity or heavy metals and low light intensity [83].
c) Increases the quantity of antioxidant enzymes and enzymes of the Calvin cycle, thus protecting the photosynthetic apparatus under cold stress [46].
d) Promote growth by activating and regulating enzymes functioning in photosynthesis like Rubisco. Additionally, BR maintains thylakoid membrane stability and regulates chlorophyll molecules by controlling the activity of the chlorophyllase enzyme [102].

### 5.2 Nutrient Uptake and Ionic Balance

Brassinosteroids increased the uptake of essential inorganic ions, decreased toxic ion accumulation, and promoted ion homeostasis [56]. Application of BR also enhanced the activities of $Ca^{2+}$-ATPase and $H^{+}$-ATPase in leaves and roots, which are responsible for regulating electrochemical gradient to maintain ionic balance to overcome the adversities of stress conditions [83].

### 5.3 Hormonal Metabolism

Under stress, BRs induced the endogenous production level of ethylene, jasmonic acid, and salicylic acid and cross-talk among these hormones in stimulating signalling pathways [99]. Application of BRs regulated the accumulation of zeatin riboside, indole acetic acid, and abscisic acid [7]. Reports have confirmed that BR and ABA regulated the expression of different stress-related genes in many plants [114].

## 6. VERSATILE ROLE OF BRS IN PLANTS

Brassinosteroids perform a versatile role in plant growth and development by influencing seed germination, cell division and elongation, photomorphogenesis, root development, stomatal development, secondary metabolism, stress tolerance (biotic and abiotic) and pollen tube formation, thus ultimately leading to an increased crop yield [38].

## 7. NATURAL OCCURRENCE OF BRS IN VARIOUS FRUIT CROPS

Though BRs was discovered in pollens of *Brassica napus*, but its different types were later identified in different organs of various fruit crops [39].

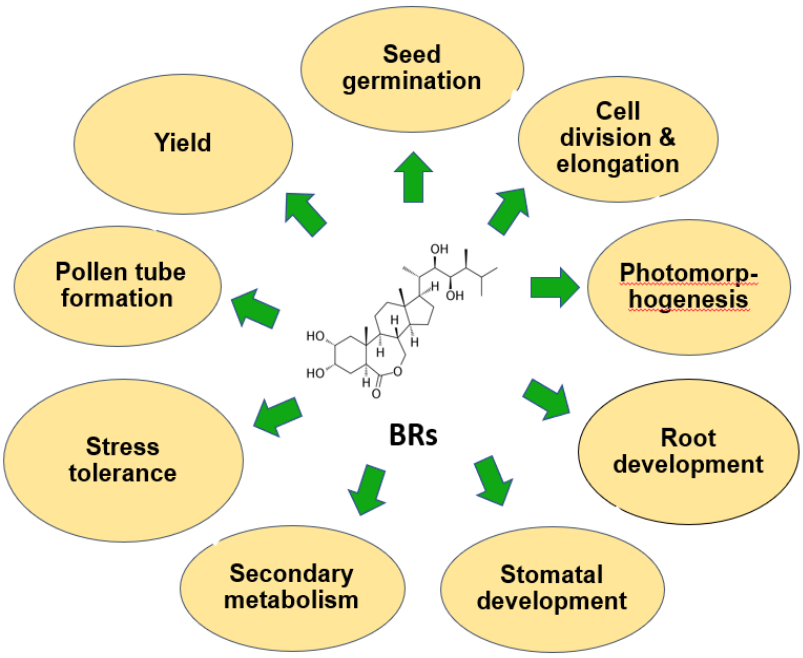


**Fig. 3. Versatile role of BRs in plants**

**Table 1. Natural occurrence of Brs in various fruit crops**

| Sl. no | Fruit crop | Plant part | Type of BRs |
|---|---|---|---|
| 1 | Loquat | Flower buds | CS |
| 2 | Satsuma mandarin | Pollen | BL |
| 3 | Sweet orange | Pollen | BL, CS |
| 4 | Bael | Leaves | 24-EBL |
| 5 | Chestnut | Galls | CS, BL, 6-deoxo CS |
| 6 | Date palm | Pollen | 24-epiCS |

*(CS: Castasterone, BL: Brassinolide, 24-EBL: 24-Epibrassinolide)*

According to [90] the samples containing BRs were purified and quantified using Gas Chromatography–Mass Spectrometry with Selected Ion Monitoring (GC–MS–SIM).

## 8. METHODOLOGICAL STUDIES OF BRASSINOSTEROIDS ON GROWTH AND YIELD OF FRUIT CROPS

### 8.1 Mango

According to Meena et al. [65] reported that after the application of BRs (80 ng/g) in mango, fruits exhibited better physical parameters and sensory scores without developing any jelly seed symptoms. In another experiment, exogenous application of EBR at optimal concentration was found to be effective for improving resistance against anthracnose caused by *Colletotrichum gloeosporioides* in mango fruit. The mode of action was by activating defense-related enzymes, increasing total phenols, flavonoids, lignins, and propectin levels, suppressing pectin hydrolases, and controlling Reactive Oxygen Species (ROS) levels and antioxidant enzyme activities in fruits of mango [84]. An experiment conducted by Zaharah [107] revealed that the application of 24-Epibrassinolide (Epi-BL or EBL) resulted in enhanced ripening, fruit softening and colour development, increased ethylene and respiration rate in mango.

When Epi-BL was administered after harvest, both the respiration rate and climacteric ethylene production increased. It accelerated fruit softening, colour development as well as fruit ripening without sacrificing the quality of mature mango fruits [106]. One time application of BR enhanced the per tree production of mango cultivar Ataulfo two applications boosted blooming and fruit set [2].

### 8.2 Banana

In order to improve the stress tolerance ability of banana plants under drought, 30 mgL$^{-1}$ of EBL application was recommended, as it boosted the antioxidant activity, and successfully decreased the plant oxidative stress, which further helped in preserving chloroplast integrity and enhancing photosynthetic capability, which enhanced plant growth, development, and production [41]. When BR was applied in conjunction with a mineral mixture, bananas' primary development features, physiological traits and their ability to withstand water stress were improved [109]. Application of 6 g/L BR increased plant height as well as pseudo-stem diameter of Berangan banana during 3$^{rd}$ week to 8$^{th}$ week compared to other treatments [110]. Rajan et al. [77] reported that the application of BR at 2 ml L$^{-1}$ as spray, first at complete opening of the bunch and then at 20 days after first spray resulted in banana bunches with higher bunch size (length and girth), finger size (length and girth), finger weight, and bunch weight.

### 8.3 Papaya

As per **[**61] proved that the combination of nutrients, particularly B, Zn, and K and BR as foliar treatment was advantageous for accelerating fruit growth in papaya resulting in good quality fruits. According to the findings of [85], the use of BR and TIBA led to an augmentation in the number and weight of papaya fruits, which in turn increased the overall yield. [24] found that the foliar application of BR on the entire canopy led to an increase in plant height, emergence of hyponastic leaves and induced a delay in both leaf senescence and subsequent leaf abscission. Mutum [69] found that foliar application of BRs was the best as it gave positive results in terms of yield, flowering, fruit set, fruit maturity, and fruit weight compared to other treatments. [64] observed that BR and ethylene (ET) can jointly regulate mitochondrial pathways in papaya fruit.

### 8.4 Pineapple

The combination of 2 mgL$^{-1}$ BRs and 200 mgL$^{-1}$ NAA when applied to pineapple plants, gave the highest crown weight, fruit weight, fruit diameter, fruit length, peel thickness, TSS and ratio of TSS/titrable acidity [22]. Yasser-Lorente et al. [105] observed that Biobras-16, a brassinosteroid analogue had a positive impact on the growth of pineapple cv. MD-2 by enhancing plant fresh weight, root number, and leaf morphology. Notably, it increased crown fresh weight without affecting fruit/crown ratios or chemical-physical characteristics, suggesting its potential as a growth promoter. [42] illustrated a promising effect of the application of DA-6 and COS in bolstering the drought resistance of pineapple plants. This positive effect was attributed to their impact on bromelain activity and mitigation of oxidative stress.

According to dos Santos [26] found that applying brassinosteroids with or without humic acid, reduced the root growth of pineapple var. Victoria, but increased leaf area and nutrient levels, influencing the yield. Freitas et al. [27] demonstrated that brassinosteroid positively influenced axillary bud development in pineapple stems by breaking dormancy and enhancing length, diameter, leaf number, fresh weight, and dry weight of aerial shoots, contributing to overall growth and yield.

### 8.5 Guava

Good quality seedlings of guava (BRS Guaraca) were produced by the application of Biobras-16 at concentrations of 0.3 to 0.6 $mgL^{-1}$, as it significantly influenced root and shoot growth of guava seedlings [25].

### 8.6 Sugar Apple

A study was conducted by Mostafa et al. [68] for two years to evaluate the effect of brassinosteroids and gibberellic acid on ten-year old sugar apple trees. They observed that combined foliar application of 1000 $mgL^{-1}$ $GA_3$ and 0.5 $mgL^{-1}$ BR at anthesis stage and then repeating the spray five times at weekly interval had positive effect on fruit set percent, total number of fruits, fruit yield, net income and fruits with lesser number of seeds.

As per [17] reported that plants which were sprayed with BR at 0.2 ppm during vegetative, flower initiation and fruit setting stages and were observed to have the highest specific leaf weight, total leaf chlorophyll content both in vegetative and reproductive stages. It gave highest yield per hectare when compared to remaining treatments.

### 8.7 Acid Lime

Application of BR at 15 ppm during petal fall, fruit development and fruit maturation stages of acid lime notably increased the fruit weight over control [103].

### 8.8 Mandarin Orange

The application of EBL at 5$mgL^{-1}$ induced disease resistance in Satsuma mandarin by modulating stress related genes [113]. Gutierrez-Villamil et al. [36] found that foliar application of BR and its analogues i.e. DI-31 reduced chilling injury in 'Arrayana' mandarin peels. This effect was attributed to diminished electrolyte leakage, membrane integrity and increased antioxidant activity and phenol content during cold storage and shelf life. The application of BR at a concentration of 2 ppm resulted in highest survival percentage and favourable vegetative growth parameters in Nagpur Orange, which included survival percentage, plant height, number of leaves per plant, number of branches per plant, stem girth, plant spread, leaf area and chlorophyll content [62].

### 8.9 Sweet Orange

As per [28] reported that BR not only preserved the sweet orange quality by reducing lipid peroxidation and hydrogen peroxide content but also improved the orange fruit's resilience to cold stress, consequently enhancing overall fruit quality.

### 8.10 GRAPES

Foliar spray of 0.2 $mgL^{-1}$ of EBL at 7 days after fruit set, at veraison stage and 30 days after veraison significantly increased fruit yield per vine and anthocyanin content of fruits in grape cv. Alphonse Lavallee [11]. Recent evidences suggested that BRs are also involved in the ripening of grapes, a non-climacteric fruit [89]. Luan et al. [59] and Champa et al. [20] reported that exogenous application of BRs at 0.4 $mgL^{-1}$ increased cluster weight, berry weight, length and breadth, berry firmness, reduced berry softening, stabilized anthocyanins, increased total phenolics, reduced berry shatter, suppressed decay, increased anthocyanin biosynthesis, reduced respiration rate and ethylene level during storage. Liu et al. [57] reported that spraying of 24-epibrassinolide at 0.4 $mgL^{-1}$ reduced berry drop, increased fruit firmness, reduced rates of respiration and rates of ethylene production during storage, decreased berry decay, increased quality attributes and controlled grey mould of table grape berries.

According to Ghorbani et al. [29] demonstrated that application of BR during post-bloom stage and veraison stage significantly enhanced berry quality and maximum total phenol and antioxidant content in grapes var. Thompson Seedless. As per [44] observed that even applying a lower concentration of BR led to formation of elongated clusters in grapes. According to Li et al. [55], application of BR significantly regulated both external and internal fruit quality. Kshirsagar et al. [53] discovered that utilizing $GA_3$ in conjunction with BR and BA (6-Benzylaminopurine or benzyl adenine) proved to be successful in promoting cell elongation and division. This resulted in enhanced berry size, increased yield, and improved quality of grapes cv. Thompson Seedless.

### 8.11 Litchi

Exogenous application of Brassinolide (BL) was effective in influencing all physico-chemical properties of litchi fruit cv. Bombai [30]. The spray of the BL solution on litchi leaves before blossom at 0.5mg, 0.75 and 1.0 $mgL^{-1}$ reduced fruit cracking rate and increased the commercial value of litchi fruit. Hence, it revealed the potential to form a standard commercial practice [74].

### 8.12 Pomegranate

The foliar treatment of 28-Homobrassinolide (HBL) at bud break influenced the growth of floral parts in bisexual flowers of pomegranate [31]. Spraying of 24-Epi-brassinolide (EBR) during the week just before full bloom, 4 weeks after full bloom and before the arils fully matures were reported not only to increase the efficiency of Ca and B in improving the aril browning disorder, but also to improve the pollen function and the fruit quality indices like fruit total soluble solids (TSS), total anthocyanin, phenolic and flavonoid content in 'Rabab' pomegranate [91].

Spraying at 0.3 $mgL^{-1}$ brassinolide gave maximum shoot length, highest leaf area, leaf nitrogen content and highest leaf phosphorous content [9]. The highest fruit set and minimum flower drop was recorded with the application of Vipul + HBL (1.5+5 ml $L^{-1}$) at 45 days after bud burst and at 10 days after fruit set [1]. The combined application of chitosan+10 and 15 µM EBR had a considerable effect on the fruit quality of late-harvested pomegranate fruit [70].

### 8.13 Passion Fruit

The brassinosteroid analogue was considered to be more efficient in increasing yield and soluble solid contents in yellow passion fruit when applied for three consecutive weeks after the appearance of the first flower [32]. The positive effect of the BR on the height, leaf area, fresh and dry masses of plants at different levels of irrigation was reported [47].

### 8.14 Phalsa

The combined application of BR and salicylic acid (SA) recorded maximum number of canes per bush, number of sprouted shoots per cane, length of shoots (cm), number of fruiting nodes per shoot, TSS (°Brix), fresh weight, juice percent and fruit yield [95].

### 8.15 Ber

In addition to delaying the senescence, brassinosteroids at a concentration of 5 µM inhibited incidence of blue mould and rot in Chinese ber [113].

### 8.16 Strawberry

According to Khatoon et al. [50] reported that when strawberry cv. Winter Dawn plants were sprayed with 0.2 ppm BR at vegetative, flowering and fruit setting stage, resulted in significant increase in total leaf chlorophyll content both in vegetative and reproductive stages, higher specific leaf weight (SLW) in vegetative, flowering as well as fruit setting stage which finally led to increased fruit yield and better quality fruits in terms of higher TSS: acid ratio, reducing sugar and total phenol content. The investigation also confirmed that the action of BR was very quick. As per [40] reported that the exogenous application of BRs improved the number of leaves, petiole length, total leaf area and number of crowns in strawberry.

BRs plays an important role in strawberry fruit ripening, and in early fruit development [19]. Brassinosteroid played a beneficial role in reducing phenolic content of strawberry mainly in the red stage [10]. Foliar application of EBL could be used to increase yield and nutritional quality of strawberry [5]. The results indicated that the foliar spray of EBL on strawberry significantly modulated the pattern and rate of fruit growth, decreased the fruit growth duration, improved yield, quality of fruits, and enhanced the precocity rate [108].

### 8.17 Apple

The pre-treatment with BR at 0.05 and 0.10 ppm concentration prior to imposing water stress helped in minimizing the deleterious effects of water stress on apple varieties i.e. Super Chief and Red Chief, however 0.05 ppm was more effective in counteracting the effect of water stress. Traits like plant height, leaf area, root-shoot fresh and dry weight and root to shoot ratio showed reductions under water stress conditions. Transpiration rate was also found to decrease under water stress conditions [88]. Foliar spray of BR (0.05 ppm) before the imposition of stress minimized the deleterious effects of water stress on apple plants [54].

The exogenous application of BR increased the expression levels of genes involved in cell proliferation. Treatments with auxin, gibberellin and brassinosteroid also affected the growth of apple trees and increased the expression of genes associated with cell growth and metabolism. These findings suggest that the interaction of gibberellin, auxin, and brassinosteroid controls growth in apple trees [112]. In conformity with [75] demonstrated that a fluoro derivative of 28-homocastasterone stimulated branch elongation in *in-vitro* grown shoots of apple rootstock *(Malus prunifolia*).

### 8.18 Pear

The time of application plays a crucial role in deciding the desirable output and the combined application of gibberellin and brassinosteroid either at $GA_3$ (100 ppm)+BR (1 ppm) or $GA_3$ (50 ppm)+BR (0.5 ppm) as pre-harvest spray at 15 days interval starting from the petal fall stage may be recommended for improving the fruit quality of Gola pear in Tarai region [94]. As specified by [45] observed that exogenous BR treatment suppressed ethylene production and delayed fruit ripening, whereas treatment with a BR biosynthesis inhibitor promoted ethylene production and accelerated fruit ripening in pear, hence BR has been suggested as a ripening suppressor.

### 8.19 Peach

Application of BL (Millagrow at 0.2%) and hydrogen cyanamide (Dormex @ 0.5%) accelerated flowering and yield in peach cv. “Florda Prince” (*Prunus Persica* L. Batch) [66].

### 8.20 Apricot

In accordance with [6] reported the usage of BR at 2 mg $L^{-1}$ as an ecofriendly way to improve the growth, yield and quality of fruits in apricot.

### 8.21 Sweet Cherry

In conformity with [60] reported that the application of brassinosteroid in cherry enhanced red colour development. In another experiment by [80], foliar applications of BR at 0.75 mg $L^{-1}$ along with postharvest application of BR 0.1 mg $L^{-1}$ and pre-harvest application of BR 0.75 mg $L^{-1}$ along with postharvest application of BR 0.2 mg $L^{-1}$ increased fruit colour of sweet cheery var. ‘Tak Danehe Mashhad’. It exhibited increased anthocyanin content, organic acids, ascorbic acid, phenol content, increased fruit weight, diameter and length with greater fruit firmness at harvest and storage.

### 8.22 Kiwi

The application of sodium nitroprusside (SNP) and 24-epibrassinolide (EBR) increased relative water content, photosynthetic pigment content and photosynthetic capacity of leaves, thus promoting root growth and biomass accumulation while decreased MDA, $H_2O_2$ and relative electrolyte leakage [100]. According to [21] reported that BR treatment improved salt tolerance in ‘Hongyang’ kiwifruit plants. In addition, the transcriptome data showed that there may be multiple genes involved in the regulation of salt tolerance by BRs and these were involved in enhanced photosynthesis, reduced $H_2O_2$ content, and reduced $Na^+/K^+$ in leaves, alleviating the salt stress injury. EBR at a concentration of 5 μM delayed the senescence in ‘Huayou’ kiwifruit during ambient storage. EBR-mediated senescence may be related to its capacity to maintain membrane lipid integrity, inhibit starch conversion as well as weaken the futile cycle of sucrose synthesis and degradation [58].

## 9. CONCLUSION

It can be concluded that in addition to the classical growth hormones, BRs and their analogues which forms the sixth group of phytohormones, have successfully proved their crucial role in modern fruit production. Enhancing the productivity, quality and modulating the ripening physiology of the fruit are the major concerns of the fruit growers. The natural phytochemicals produced endogenously during fruit development by playing a vital role in regulating the various process involved in fruit development, ripening and quality. Whereas exogenous application of BRs specifically influences the physiological processes during the different growth period of fruit production resulting in enhanced fruit quality, yield and by also influencing the defence mechanism to tolerate various biotic and abiotic stresses. Thus, it can be considered as a game changer in the modern fruit industry.

## 10. FUTURE PROSPECTS

- Dosage and stage of application of BRs on higher plants including all fruit crops has to be standardized.

- Studies on the possibility of using BRs in imparting freezing and heat tolerance capacity in fruit crops has to be conducted.
- In-depth studies on cross-talks of BRs with other PGRs has to be carried out.
- Research has to be conducted to find out the mechanism behind the role of BRs in extending the shelf life of fruits.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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