J. Indian bot. Soc. e-ISSN:2455-7218, ISSN:0019 - 4468 Sp. Issue Vol. 100 (A) 2020:114-124

NOVEL PLANT HORMONES- A REVIEW

[1]POONAM MEENA, [2]SAMPAT NEHRA AND [3]P. C. TRIVEDI

[1] Department of Botany, University of Rajasthan, Jaipur, India,[2] Department of Biotechnology, Birla Institute of Scientific Research, Statue Circle, Jaipur, Rajasthan, India,
[3]Vice Chancellor Jai Narain Vyas University, Jodhpur
Email
DOi

Phytohormones are group of naturally occurring compounds secreted by plants which are synthesized at one place and translocated to another where they regulate the growth and differentiation , process of reproduction and even death. These phytohormones are required for appropriate stimulus when plants are subjected to stress or unwanted environment. Plant hormones, including auxin, cytokinin, abscisic acid, gibberellins, ethylene and recently evolved group of novel phytohormones including brassinosteroids, salicylic acid, jasmonates, polyamines, strigolactones and peptide hormones , significantly exhibit different functions in plant at cellular and molecular levels. The discovery of new class of phytohormones is new era of research in science to evaluate their various effect upon growth and development of plants.

Keywords: Brassinosteroids (BS), jasmonic acid(JA), peptide hormones(PH), polyamines(PA) and salicylic acid(SA)

Phytohormones are group of naturally occurring chemical compounds of plants required in small concentration and rarely effective at their synthesis, but regulate site of variety of physiological and morphological processes. Multiple hormones often influence a single process while single phytohormone can regulate many developmental and cellular processes at the same time. Novel Plant hormones, including brassinosteroids, salicylic acid, jasmonates, polyamines, strigolactones and peptide hormones beside conventional auxin, cytokinin, abscisic acid, gibberellins, ethylene phytohormones, are also able to regulate different functions in plants at cellular and molecular levels either individually or in crosstalk. Continuous effort has been made worldwide to explain their biosynthesis, mechanism of action, physiological role, interplay with other hormones and their potential of stress management. This article will review briefly about novel or sixth group of plant hormones with special consideration of brassinosteroids.

Salicylic acid/(SA): Raskin (1992) was introduced salicylic acid as a plant hormone. SA is a water soluble non-enzymatic antioxidant which acts as a plant growth regulator for different plant physiological processes like photosynthesis, shoot and root development, flowering and senesence (Koo *et al.* 2020). SA combat abiotic stress (Sharma *et al.* 2020) and biotic stress (Ding & Ding 2020) respectively.

Jasmonic acid/(JA): Demole *et al.* (1962) isolated secondary metabolites as Jasmonic acid from the jasmine flower oils. Various developmental processes like vegetative growth, trichome development, anthocyanin biosynthesis, senescence and cell cycle regulation governed via JA (Gomi *et al.* 2020). Jasmonates have also been recognized as defence hormone which regulate various biotic and abiotic stress responses (Ruan *et al.* 2020 and Yang *et al.* 2019).

Polyamine/(PA): Polyamines (PA) are aliphatic amines, ubiquitous bioactive compounds occurring in microbes, plants, animal, and human semen and their main compounds are Putrescine (Put), spermidine (Spd) and spermines (spm), which exist mainly in free form inside higher plants. Since PA are fully protonated, they have been shown to bind to cell membrane and cell wall. PAs are key compounds in plant physiology (Takahashi 2020) such as for embryogenesis, organogenesis, senescence, fruit maturation and development. Polyamines played a significant role in biotic and abiotic stress (Sun *et al.* 2018 , Chen *et al.* 2019 and Yu *et al.* 2019) management in plants.

Peptide Hormones/PH: Current research suggests that many secretory and nonsecretory peptide signals involved in multiple facets in growth and development of plant. Identification of these peptides involved biochemical purification method. Such peptide including, *SYSTEMIN* (defence), *PHYTOSULPHOKINE/PSK* (somatic embryogenesis), *CLV3* (homeostasis or water stress), *RAPID ALKALINIZATION FACTOR/RALF* (arrestss growth of root), *ENOD40* (nodule development), *POLARIS/PLS* (vascularization and expansion), *INFLORESCENCE DEFICIENT IN ABSCISSION* /IDA (organ abscission) etc. respectively (Matsabyashi and Sakagami 2006, Takahashi *et al.* 2018). Various peptides identified as membrane bound receptor kinase belonging to largest receptor like molecule family, significantly influence the plant growth and development (Gancheva 2019). These proteinases are involved in protein digestion of attacking pests (Hirakawa and Sawa 2019).

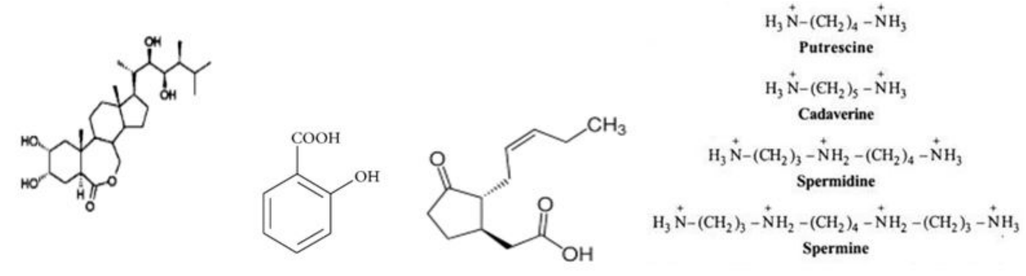
Strigolactone/(SL): Cook *et al.* (1966) first isolated strigol as a natural stimulant of *Striga lutea*, germination then these compounds were termed as strigolactones. SLs stimulates hyphal branching via AM symbiosis and support plant in uptake of available mineral nutrients like phosphate or in phosphate scarcity they produce higher amount of strigolactones (Mishra *et al.* 2017 and Bounmeester *et al.* 2019). SL promote seed germination in parasitic plants. It combat drought, salinity nutrition and temperature stress via AM symbiosis (Ruiz-Lozano,2016) and it confers immunity against *Pseudomonas syringae, Rhodococcus fascians* and *Pectobacterium carotovorum* (Stes *et al.* 2015).

Brassinosteroids: Naturally occurring brassinosteroids (BRs) are a polyhydroxy steroidal hormone, or known as sixth class of plant hormone. They have been isolated from many plants including fresh water and brown algae, monoplast, gymnosperm, dicots and monocots, (Fung and Sidall 1980). These hormones were explored when Mitchell *et al*. (1970) used organic extract of *Brassica napus* pollen treatment which induced cell division and stem elongation. Brassinolide is the most abundant and bioactive crystalline form and its structure determined by Grove *et al.* (1979) by X-ray crystallography. Individual species having variable distributions of BRs among different tissues like immature roots, seeds and flowers and pollens, have the large amount of BS upto 1–100 ng/g fw (fresh weight) whereas leaves and shoots contain lesser amounts 0.01–0.1 ng/g fw (Thompson *et al*. 1982). Brassinosteroids play significant contribution in various disciplines of plant biology, involving cell division cell differentiation and elongation, shoot and root growth, seed germination, stomatal movememt photo-morphogenesis, and fertility (Mitchell *et al*. 1941,1970 Laura *et al.* 2019 and Nolan *et al.* 2020) similar to animal hormones. BR have exclusive importance in mediating various abiotic stress like thermal, salinity, drought, freezing, metal toxicity and biotic disease stress. Extensive research upon brassinosteroids imply, that it has the potential to enhance quality and quantity of horticultural crops and save plants against biotic and abiotic stresses exiting in the local environment (Kang & Guo 2011).

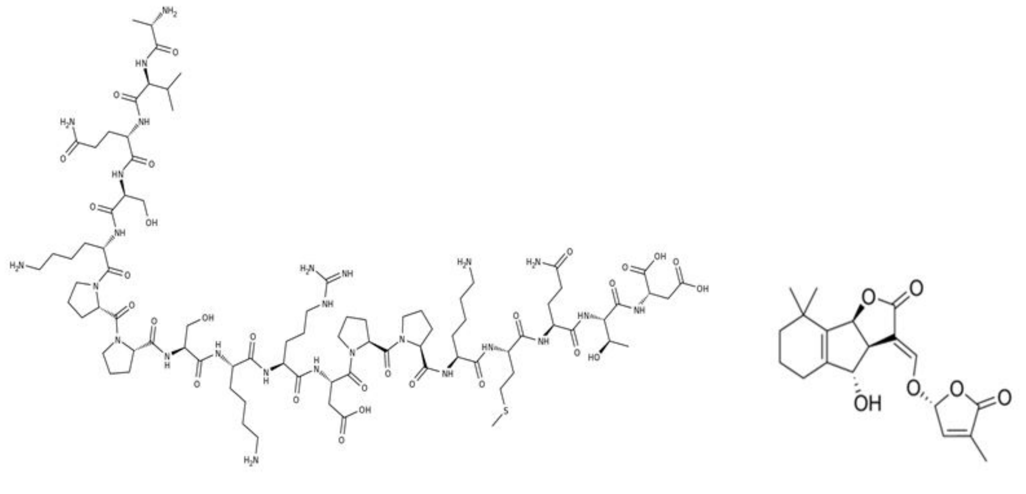
Interplay between BRs and other plant hormones regulate a wide range of developmental and physiological processes. BRs depend on their crosstalk with other hormones like auxins and gibberellins for long distance effect. Exogenous application exhibit that excess BRs can be metabolize rapidly as plants synthesize them continuously to regulate their own growth and development.

Brassinosteroids (Brs) Cross Talk with

General structure of Novel hormones is given in Figure 1



Brasinosteroid **Salicylic acid** **Jasmonic acid** **Polymine**



Systemin **Strigolactone**

Phytohormones:

BR and Auxin: BR and auxin are considered as potent phytohormones which significantly function as key regulators in different plant development processes such as hypocotyl elongation, stem elongation and root development (Zheng *et al.* 2019). Beside their coactive interplay, sometimes both interact antagonistically to control cell elongation, stem cell maintenance, gene expression control in root tips. Still balanced concentration of both hormones is needed for proper development of root in apple (Chaiwanon 2015 , Zheng *et al.*2019 & Ahmad *et al.* 2018).

BR and Gibberellin (GA): Clouse *et al.* (1996) reported , promising evidence of their interaction in between GA- and BR-deficient mutants of *Arabidopsis*, with the discovery of the (being de-etiolated in the dark and dwarf stature in the light) remarkably resembled phenotypes. Crucial role of BR signifies genome expression in the GA regulation . The studies that indicated around 66.7% of brasinosteroid required for gene regulation of GA (Bai *et al*. 2012). GA promoted hypocotyl elongation was diminished in seedlings of *Arabidopsis* with lower biosynthesis of brassinosteroid, therefore both hormone are required for cell elongation (Gallego *et al.* 2012) while growth defective BR mutants can be rescue with GA (Peres *et al*. 2019).

BR and Cytokinin (CK): Cross talk between CKs and BRs associated with plant growth regulation. BR showed an prominent growth of lateral roots, thus their promising interplay regulate growth and development of plant (Vercruyssen *et al*. 2003 & Ahmad *et al.*2018).

BR and Abscisic Acid (ABA): Up regulation of BIN2 and down regulation PP2C gene family mediates the BR signalling which is regulated by ABA (Zhang *et al.* 2009) causing decrement in BRs signalling pathway. Stomatal closure, root growth, seed germination, seedling formation significantly support the negative interplay between these hormones (Steber *et al*. 2001 & Takahashi *et al.* 2018). Usually defective BR signaling mutants (i.e, de-etiolated-2 mutant (det2), bin2-1, bri1, constitutive photo morphogenesis and dwarfism (cpd) posses high ABA senstivity at the time of primary root formation, germination of seed and early seedling development, (Li *et al*. 2001, Nolan *et al.* 2017 & Fabregas *et al.* 2018).

BR and Ethylene (ET): Exogenous BR treated *Arabidopsis* seedlings exhibit increased ethylene biosynthesis level via an increase in ACS5 protein stability with its half life increment (Hensen *et al*. 2009) and ACS stability improved with high BRs which resist its degradation against 26S proteasome. Contrary to this, low concentration of BRs suppresses the ethylene biosynthesis with the enhanced level of BZR1/BES1 and main BR. Externally application of BR achieved good quality of fruiting, postharvest ripening via enhance ethylene production by increasing ACS2 and ACS4 genes transcription in *Solanum lycopersicum* (Zhu 2015, Fabregas *et al.* 2018 and Peres e*t al.* 2019).

Physiological Effects of BR

Cell Elongation and differentiation: BR application at nM to µM levels was effective in hypocotyl, peduncle and epicotyl, mesocotyl and coleoptile elongation (Clouse 1996). Endogenous BRs directly involved in cell expansion control in young vegetative tissue particularly while exogenous BR application were also found to be promising for plant growth with the xyloglucanase and expansin gene transcription, which promote cell wall loosening which in truns leads to stem elongation (Nolan *et al.* 2020).

Shoot and Root and leaves development: Remarkable increase in shoot and root growth was reported upon exogenous BR application (Hong *et al.* 2002). BRs regulate various physiological and developmental processes, including leaf growth as treatment of leaf mass and per unit leaf area of leaf (Sun *et al.* 2015). BR application was significantly increased during stress in some key processes like photosynthesis, carotenoid and chlorophyll content in cucumber (Li *et al.* 2016 & Nolan *et al.* 2020).

Pollen and Reproductive Biology: BR mutants have reduced fertility so brassinosteroids are also known as fertility hormone. Endogenous BR concentration is high inside pollen as it elongates the pollen tube suggested by *in vitro* studies (Hewitt 1985). Haploid production is favored by pollination initially and brassinolide treatment in *Arabidopsis thaliana* and *Brassica juncea*, induced haploid seed formation which later developed into stable plants (Kitani 1994).

Senescence: BRs accelerate senescence in normal plants evident with BR mutants which exhibit delayed senescence in *Arabidopsis* (Szekers *et al*. 1996). 24-epibrassinolide reduces malondialdehyde levels by oxidative degradation of lipids which was found to be a membrane protectant therefore remarkable delaying senescence observed (Ershova 1996 & Peres *et al.* 2019).

Brs Combat Stress in Plants: Human consumption of residual pesticides indirectly from vegetables and fruits gets reduced with an exogenous BRs application which display improved metabolism of pesticides and their removal in cucumbers. Research findings indicate that Brassinosteroids regulate the antioxidants and activities of antioxidative enzymes like glutathione reductase, catalase, guaiacol peroxidase, ascorbate peroxidase and superoxide dismutase to provide safeguard of plants under stress. Structural analogs of Brs have also been involved in the development, antioxidation, lipid peroxidation and protection. Application of BRS will reduce the oxidative stress in chickpea, soyabean, potato, rice and improved growth in plants recorded (Mazorra *et al.* 2002, Ozdemir *et al.* 2004, Almeida *et al.* 2005, Gruszka 2018 Peres *et al.* 2019, Nolan *et al.* 2020).

Biotic Stress: Plant resistance was induced by BRs, as exogenous application of BR to early field crop plants render immunity against various pathogenic infections (Yu *et al*. 2018). Exogenously BRs application enhance barley plants resistance against diverse pathogenic fungi (Ali *et al.* 2013). *Phytophthora* infection was significantly reduced in BRs treated seedlings of potato with the elevated level of phenolic, terpenoid compounds, ABA and ethylene level. BRs induced disease resistance mechanism is associated with the polyphenol metabolism via enhanced activities of polyphenoloxidase and peroxidase enzymes in cucumber plants. Virus infection reduced with BRS treated early plant seedlings (Rodkin *et al.* 1997) and yield increased upto 56%. Nakashita *et al.* (2003) reported that BRs treated plants remarkably reduced incidence of bacterial disease of Rice like bacterial blight (*Xanthomonas oryzae*) and rice blast (*Magnaporthe grisea*), respectively. Brassinolide treated egg masses of plant parasitic root knot nematode, *Meloidogyne incognita* significantly enhances hatching percentage (Ohri *et al.* 2002).

Abiotic Stress:

Salinity Stress: Sasse *et al.* (1995) reported 24-epibrassinolide treated seeds of *Eucalyptus camaldulensis,* under saline conditions resulted in good seed germination. BRs treated lettuce plants, have potential of ACC level reduction with ethylene production, consequently escape premature death and perfect protection effect to plants under salinity (Mayank *et al.* 2004 & Peres *et al.* 2020). Saline medium containing rice seeds treated with BRs reinstate pigments considerably high rather than untreated plants under the same conditions (Anuradha and Rao 2003).

Thermal Stress: Chilling stress at 1-5^{o} C was encounter with the 24-epibrassinolide application on rice, maizes pepper and cucumber (Rao *et al*. 2002 amd Anwar *et al.*2018) which significantly induced the photosynthesis rate, chlorophyll pigment, carbohydrate assimilation and regulated the required gene expression to mitigate the chilling stress. Increased ATP, Super oxide dismutase activity and proline level involved in the freezing tolerance in plants treated with BRs via osmoregulation and membrane stability (Li *et al.* 2017). Mitochondrial small heat shock proteins (MT-sHSP) expression was induced with the treatment of 24-epibrassinolide upon tomato plants at 38^{0} C or high temperature reported by Singh and Shono (2005) that imply thermotolerance has also achieved with application of Brs.

Drought Stress: Nilovskaya *et al.* (2001) reported that BRs involved in improved resistance of plants under drought conditions and BRs treated such crops significantly increased crop yield value. 24-epibrassinolide solutions sprayed early seedlings were found to show their leaves to have large water content. Kagale *et al.* 2007 found that (*A. thaliana* and *B. napus* seedlings) 24-epibrassinolide confers tolerance via altered expression of drought responsive genes under drought conditions in BRs treated plants have elevated level of stress responsive genes and membrane stability substances (osmoprotective metabolites) involved in antistress management process (Fàbregas *et al.* 2018).

Heavy Metal Toxicity Stress: Application of Brassinosteroids to different plants and crops renders the lowering of ingestion and accumulation of such heavy metal elements.

Treatment of 24-epibrassinolide reduced the absorption of radionuclidesfrom cesium (Cs) and strontium (Sr) ions rich barley crop soil (Khripach *et al.* 1997). Epibrassinolide blocked the heavy metal (zinc, cadmium, lead and copper) accumulation in *Chlorella vulgaris* cells (Bajguz 2000) while mung bean (*Phaseolus aureus)* seedlings ameliorated Aluminium (Al) toxicity with the treatment of brassinosteroids with improved chlorophyll content and growth under Aluminium stress condition (Abdullahi *et al.* 2003). 28-Homobrassinolide treated nickel (Ni)-stressed *B. juncea* plants improved the seedling growth by increasing the activities of nitrate reductase and carbonic anhydrase enzymes, rate of photosynthesis and chlorophyll pigment (Alam *et al.* 2007). Ultimately BRs reciprocate the oxidative toxic metal stress via antioxidant enzyme introduction (Sharma *et al.* 2018).

CONCLUSION

Brassinosteroids are native, nonhazardous economic and ecofreindly compounds which significantly improve the crop productivity of unfertilized fields in lower concentration thus serve as potential tool for improvement of ecology and agriculture under extreme stressed environment. Latest technology focused upon stable synthetic BRs analogues formation and their genetic manipulatio which may become a suitable and effective strategy for larger yields of crop (Kang and Guo 2011). Since last many decades researcher constantly cover biochemical, structural, molecular and genomic approaches to elucidate mechanism brassinosteroid asction in growth, development, cross talk, biotic and abiotic stress response but despite such progress, there are still some unanswered puzzles exist in their mechanism or signaling. Advance technologies like Proteomics (Song *et al.* 2018) and genomics (Shahan 2019) via computational modeling may explore the genetic regulation of gene involved in induction and suppression of BRs mediated response.

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