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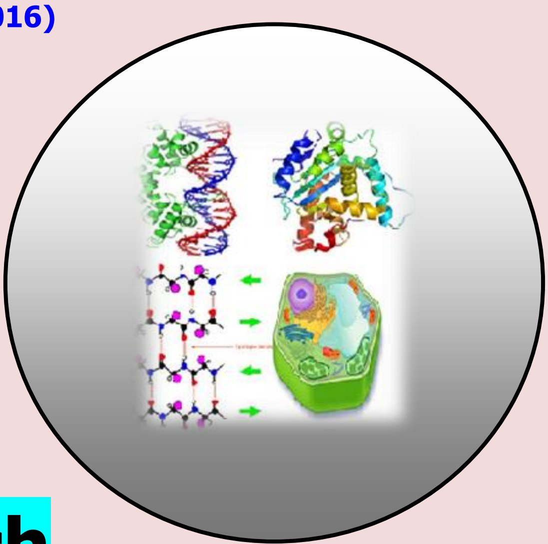

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# Brassinosteroids: A New Plant Growth Regulator

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**ABSTRACT**

***Brassinosteroids (BRs) are included under polyhydroxylated steroidal hormone which plays a significant role in regulating plant metabolism and developmental processes under stressed or non-stress condition. BRs have an extensive distribution in the plant kingdom and have been confirmed to play a role in stem elongation, pollen tube growth, leaf bending and epinasty, root growth inhibition, induction of ethylene biosynthesis, proton pump activation and xylem differentiation. Beside this, they also specifically regulate the expression of genes.***
***Keywords: Brassinosteroids and Polyhydroxylated.***

## INTRODUCTION

Brassinosteroids are steroidal plant growth promoting hormones that occurs ubiquitously in plant kingdom. These plant steroids are essential regulators for variety of physiological processes such as organ elongation, vascular differentiation, male fertility, timing of senescence, and leaf development. BRs are considered as plants hormones with pleiotropic effects (Sasse, 1997). BRs play a pivotal role in germination, growth, cell division, thickening promotion, regains its natural position under natural condition (Mandava, 1988).

Brassinolide (BL) and Castasterone (CS) occur ubiquitously in plant kingdom. Also, these compounds are similar to BRs on steroidal basis. Today, about 65 BRs have been extracted and their structures were also characterized (Bajguz and Tretyn, 2003). BRs plays a crucial role in developmental processes, such as photo-morphogenesis, reproductive development, leaf senescence, etc (Choudhary et al., 2012). BRs are mainly found in shoot and seeds of the plants, such as *Arabidopsis thaliana* (Fujioka et al., 1996). Main source for BRs production is pollen. Immature seeds also have abundant amount of BRs. leaves does not contain large amount of BRs (Takatsuto et al., 1989).

## OCCURRENCE OF BRs

Brassinosteroids have been extracted from different parts of the plants. The levels of BRs are varied from plant to plant, species to species and also differ in their parts. Some of the related data are summarized in Table 1.

**Table 1. Endogenous level of BRs in various pants parts [Data collected from Fujioka et al. (1997), Bajguz (2007)].**

| Species | Tissues | Levels (mg $g^{-1}$ f.w.) |
|---|---|---|
| *Arabidopsis thaliana* | shoot, seed, silique | 0.11-5.4 |
| *Brassica napus* | pollen | >100 |
| *Brassica compastris* | seed, sheath | 0.00013-0.094 |
| *Raphanus sativus* | seed | 0.3-0.8 |
| *Helianthus annuu* | pollen | 21-106 |
| *Vicia faba* | pollen, seed | 5-628 |
| *Pisum sativum* | seed, shoot | 0.164-3.13 |
| *Solanum lycopersicum* | shoot | 0.029-1.69 |
| *Pinus thunbergii* | pollen | 89 |
| *Cupressus arizonica* | pollen | 1.0-6400 |
| *Catharanthus roseus* | cultured cells | 0.047-4.5 |
| *Equisetum arvense* | strobilus | 0.152-0.349 |
| *Hydrodictyon reticulatum* | green alga | 0.3-0.4 |
| *Oryza sativa* | shoot | 0.0084-0.0136 |
| *Thea sinensis* | leaves | 0.001-0.02 |
| *Citrus sinensis* | pollen | 36.2 |
| *Zea mays* | pollen, shoot | 2.0-120 |
| *Lilium elegans* | pollen | 1.0-50 |

## BIOSYNTHESIS OF BRs

There is a structural relationship between the BRs and phytosterol. These two structures are resembled to each other on the basis of carbon skeleton. BRs are prepared from the Castasterone (CS) in crown gall cells of *Catharanthus roseus* (Yokota et al., 1990). In early days, it is proved that the biosynthetic pathway TeS-TyS-CS-BL operates in both cells, such as crown gall and normal cell of *Catharanthus roseus* (Fujioka et al., 1997). The basic features of BL biosynthesis were exposed utilizing cell suspension cultures of *Catharanthus roseus* that were fed deuterated and tritiated putative intermediates in BL biosynthesis followed by analysis with receptive techniques of GC-MS to observe alteration of the labelled compounds (Fujioka and Yokota, 2003). Based on side chain arrangement and stereochemistry, extensive distribution in the plant kingdom and the comparative biological activities in bioassays, it was predicted that the plant sterol campesterol would be rehabilitated to BL via teasterone, typhasterol and castasterone (Yokota et al., 1991).

This pathway, in addition to numerous midway steps was confirmed in *Catharanthus roseus* cells and seedlings. Moreover, it was found that C-6 oxidation could occur before (Early C-6 oxidation pathway) or after (Late C-6 oxidation pathway) hydroxylation of the side chain (Fujioka and Yokota, 2003; Fig.1).

## REGULATION OF PLANT METABOLISM WITH BRs

Plants development is partially or completely depend on the regulation of hormones. Hormones play an essential role in the developmental processes. BRs follow the paracrine nature of action (Montoya et al., 2005). It plays some important functions in the metabolism of plants. BRs are involved in hormonal regulatory mechanisms and this mechanism involved in the organ initiation and developmental process (Vert et al., 2005). BRs levels within the cell is regulated by different approaches, such as breakdown, synthesis, and conjugation. Recently, a leucine-rich protein (BRL 1) has been discovered from (*Arabidopsis thaliana*) which is included as a BRs receptor. In most of the animal systems, receptors for steroid hormones are intracellular. The BRs receptor (BRL 1) is located in the plasma membrane and functions at the cell surface and transduces extra-cellular signals (Li et al., 1997). The binding of BRs molecules to the receptor of kinase leads to the activation and subsequent phosphorylation of additional kinases and/or phosphotases (Clouse et al., 1996).

## RELATIONSHIP OF BRs WITH PHYSIOLOGICAL FUNCTION

BRs are supposed to control the growth, development and other physiological processes in plants (Bajguz, 2007). BRs are also known to influence various developmental processes, including seed germination, cell division, cell elongation, flowering, reproductive development, senescence, elongation, banding, vascular development, membrane polarization, proton pumping, source and sink relationship (Arteca, 1995; Marquardt and Adam, 1991; Meudt, 1987). BRs are more effective in stimulating the growth of young vegetative tissues (Sasse, 1991). BRs promoted elongation of soybean (Yopp et al., 1981), mung bean (Gregory and Mandava, 1982), azuki bean (Mandava, 1988) and pea epicotyls (Clouse et al., 1996), bean (Mandava et al., 1981), sunflower and cucumber hypocotyls (Katsumi, 1985), *Arabidopsis* peduncles (Clouse et al., 1993) and wheat coleoptiles (Sasse, 1985). BRs are also very helpful, to destroy the fungal and insects developments that damage the whole plant (Chory et al., 1996). Response of plants and functions are in a concentration dependant manner (Clouse, 1997) and higher concentration may cause the cell death. BRs concentration from nano meter to micro meter levels is sufficient for elongation of various parts of plants, such as hypocotyls, epicotyls, and peduncles of dicots. It also promotes monocots coleoptiles and mesocotyls (Mandava, 1991). Endogenously release BRs are directly involved in the regulation of cell expansion.

Cell division is very important phenomenon for plants growth. Dwarf plants having very low or negligible amount of hormones, due to this reason, cell size is reduced and plant become remains dwarf (Kauschmann et al., 1996). Cytokinin inhibits the process of senescence while 24-epibrassinolide promotes that processes (He et al., 1996). It was reported by Wang and Zeng (1993) that rate of electrolyte leakage is reduced at the temperature of 1-5 $^{0}$C in the presence of 24-epibrassinolide whereas proline content and ATP count is increased. Extensibility of wall in soybean epicotyls is increased in the presence of BR within two hours of treatment. It might be due to increased mRNA levels by BRU1. This gene was supposed to act in similar way as that of XETs (Zurek and Clouse, 1994). When brassinolide is given to the plant (alone or in combination with auxin), the percentage of transversely oriented cortical microtubule is increased as compared to non treated plant (Mayumi and Shibaoka, 1995). IAA and 24-epibrassinolide have same effect in wheat coleoptiles at concentrations of $10^{-7}$M and $10^{-6}$M (Golovatskaya, 2004). BRs can initiate the cellular mechanism during the course of seed germination (Zadvornova et al., 2005) and also regulate the events of cell cycle (Gonzalez-Garcia et al., 2011). It stimulate the growth of hydroponics plants (Arteca and Arteca, 2001), and manage the cellular mechanism of leaf cells (Nakaya et al., 2002).

BRs biosynthetic mutants plants like, *Arabidopsis thaliana* (Tao et al., 2004) and *Pisum sativum* (Nomura et al., 1997) proved that BRs are major plant growth regulator. Some dwarf species of *Arabidopsis*, protect through the application of BRs (Bishop and Yokota, 2001). BRs play a significant role in growth and development alone as well as in combination with some other hormones, such as auxin, gibberellins, cytokinins (Domagalska et al., 2010), ethylene (Manzano et al., 2011), salicylic acid (Divi et al., 2010), and jasmonic acid (Creelman and Mullet, 1997) to enhance the metabolism of the plants. BRs have been applied to the plant at various stages like vegetative stage (Vardhini and Rao., 1998), flowering stage (Vardhini, 2013), meiosis stage (Saka et al., 2003), grain filling stage (Vardhini, 2012), anthesis stage (Liu et al., 2006), foliar stage (Vardhini et al., 2008) and also through various methods such as seed treatment (Zhang et al., 2007), shotgun method (Hayat et al., 2010) and others (Bajguz and Hayat, 2009); BRs regulate the function of various genes, and affect the metabolic pathways which contribute to the regulation of cell division and differentiation (**Fig. 2**).

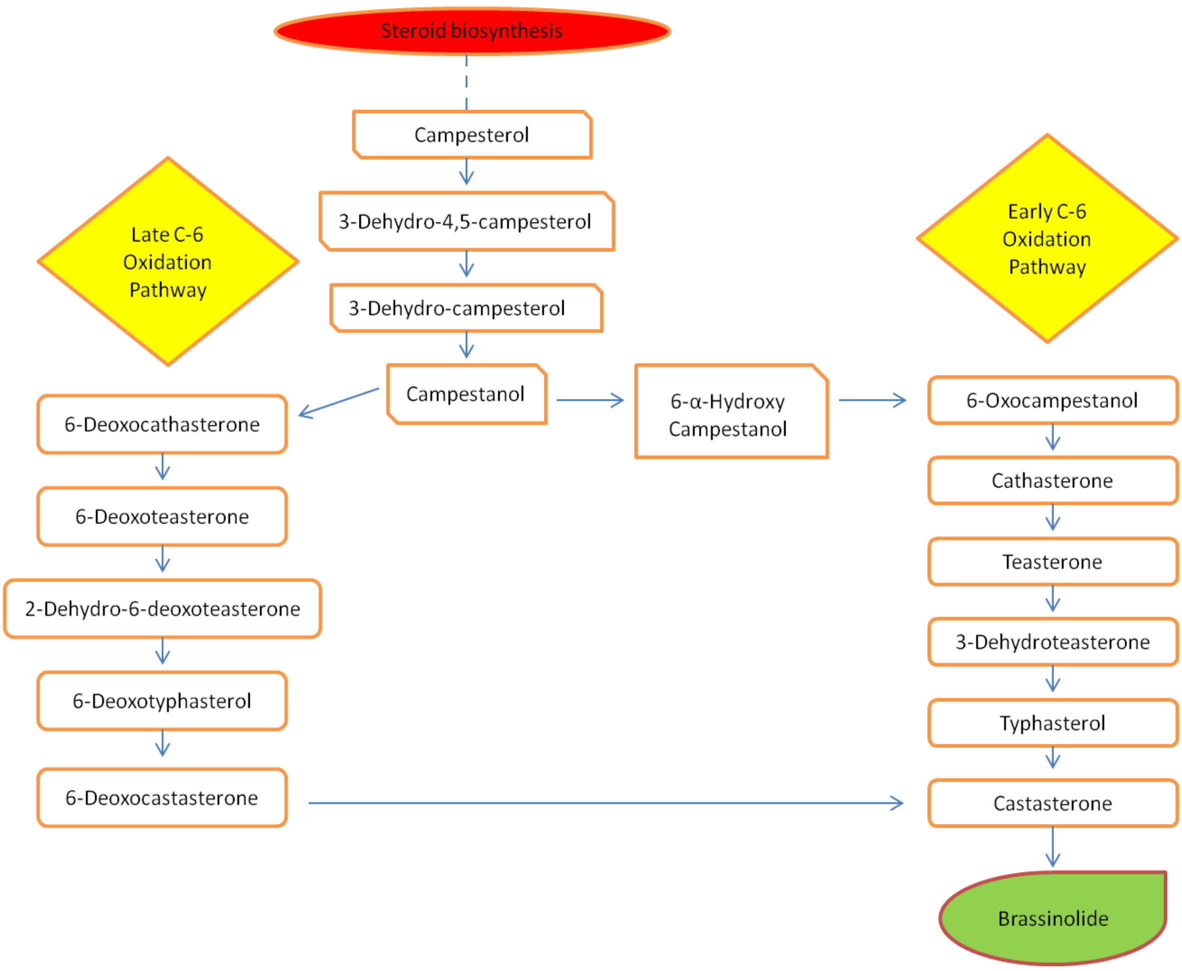


**Fig. 1. Biosynthesis of BRs**

**BRs and photosynthesis**

Photosynthesis is a process in which the solar energy is captured by chlorophyll and excitation of electrons takes place and sequence of enzymatic reactions occurs which assimilate $CO_2$ to synthesize carbohydrates along with the liberation of oxygen (Pan et al., 2012). It was observed that just after the treatment with HBL the Hill reaction activity decreased but at later developmental stages the activity was enhanced.

Some studies reported that *ϕPSII* is found to be increased in presence of BRs (Yu et al., 2004; Jiang et al., 2012; Hu et al., 2013; Li et al., 2016). The reduced content of chlorophyll can be restored by the application of BRs like BL, EBL and HBL (Anuradha and Rao, 2003) which ultimately regulate the photosynthesis. It is a well-established photosynthetic rate and its related attributes decrease under salt stress (Ashraf, 2004), however, BRs were reported to reverse the damage to photosynthetic machinery. It was reported by Hayat et al. (2010) that *Vigna radiata* experienced a significant decrease in the levels of photosynthetic rate, SPAD chlorophyll and fluorescence in the presence of salt stress but HBL partially overcome the damage caused by salt. The relative water content, chlorophyll and photosynthetic rate of wheat suffering from drought stress increases in presence of HBL (Sairam, 1994). Application of EBL induces thermotolerance in rape and tomato plants (Dhaubhadel et al., 1999; Singh and Shono, 2005). The decrease in the net $CO_2$ assimilation rate due to heat stress is also restored by EBL (Thussagunpanit et al., 2015). One of the first studies related to the effect of BRs on the plants under cold stress was reported by Hamada (1986). Chl *a* and *b* content in plants decreases when plants are subjected to cold treatment (Wise and Naylor, 1987). The ability of BRs to regulate the uptake of ions into plant cells can be exploited to reduce the accumulation of heavy metals and radioactive elements in plants. The toxicity effects and symptoms produced heavy metals in relation to photosynthesis are minimized by BR application (Bajguz and Hayat, 2009). Our results indicate that BRs play an important role in regulating synthesis and activation of a variety of enzymes in the photosynthetic apparatus.

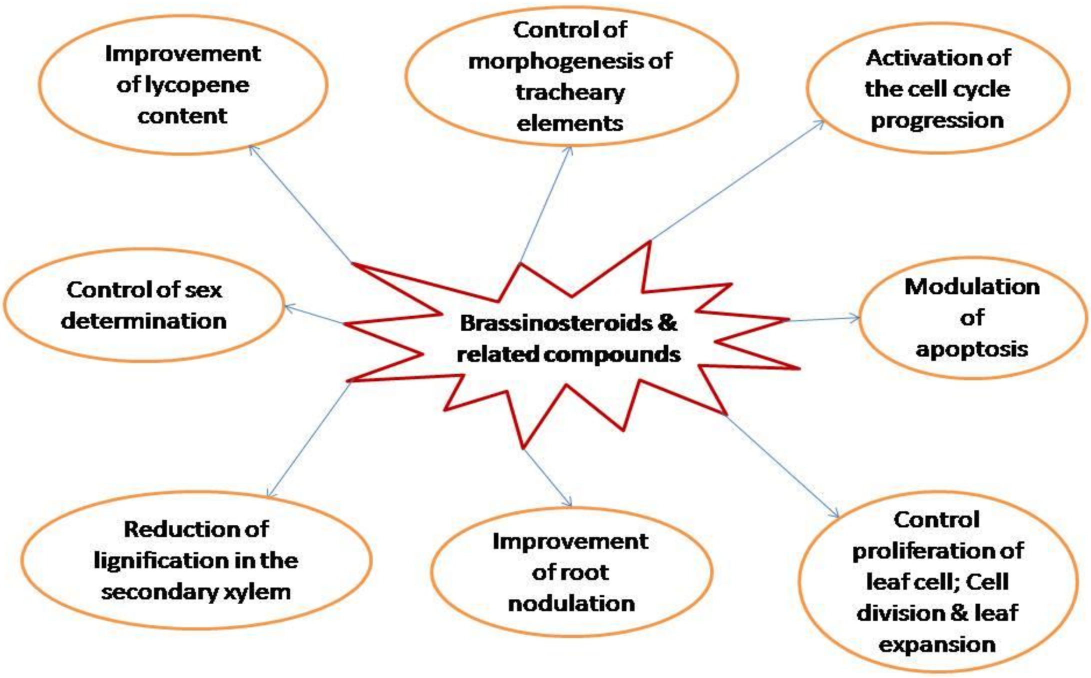


**Fig. 2 Roles of BRs in plants.**

**Relation of BRs with oxidative stress and antioxidant system**

Plants are autotrophic and use radiant energy to perform all the cellular mechanism of own cell. Despite this plant have classical metabolic pathways. This pathway helps in the utilization of its energetic potential in aerobic condition (Navrot et al., 2007). When the antioxidant system suppress by some factors, the oxidative stress may cause various harmful changes in the lipid, proteins, and nucleic acids. This phenomenon also causes a one relevant change in the system which is known as distribution of the redox homeostasis, (Gille and Sigler, 1995).

Plants protect themselves from various stresses through number of antioxidant enzymes, such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), etc. (Simonovicova et al., 2004). Beside this, some have non enzymatic antioxidants such as ascorbate, glutathione, carotenoids, etc. (Ozdemir et al., 2004; Sharma and Dubey, 2005). Role of BRs in the antioxidant system is important because some parameters increased/enhanced while some are retarded when BRs treatment is given to the plants. In some plants such as sorghum, BRs increase the activity of CAT while the activity of POX and ascorbic acid was retarded under osmotic stresses (Vardhini and Rao, 2003). BRs can stimulate the antioxidant system to increase the tolerance of various crops. It was reported that application of BRs increases the accumulation of proline and enhanced the activities of various antioxidant enzymes in salt stressed *Cicer arietinum* (Ali et al., 2007) and *Vigna radiata* (Hayat et al. 2010). Kagale et al. (2007) demonstrated that epibrassinolide has an ability to ameliorate NaCl-induced inhibition in seed germination of *Arabidopsis thaliana* and *Brassica napus.* In addition, Li et al. (2012) reported that epibrassinolide induces changes in antioxidative enzymes under drought stress. Besides these BRs also decrease the MDA content and electrical conductivity of leaves under drought stress (Zhang et al., 2008). BRs also reported to decrease the low and high temperature stress in various crops (Singh and Shono, 2005; Kagale et al., 2007; Janeckzo et al., 2007). Moreover, BRs also minimize the toxic effect generated by excess of heavy metals (Bajguz and Hayat, 2009).

## CONCLUSION

It has been concluded that BRs have the ability to improve the quality of the various crops and also increase the productivity of the crops. BRs also protect plant from various kinds of stresses. Therefore, it can be regulated as a new plant growth regulator.

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