Ecotoxicology and Environmental Safety 147 (2018) 935–944

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Review

Role of 24-epibrassinolide (EBL) in mediating heavy metal and pesticide induced oxidative stress in plants: A review

Babar Shahzad[a,*], Mohsin Tanveer[a], Zhao Che[b], Abdul Rehman[c], Sardar Alam Cheema[c], Anket Sharma[d], He Song[b], Shams ur Rehman[e], Dong Zhaorong[b]

[a] School of Land and Food, University of Tasmania, Hobart, Tasmania, Australia
[b] School of Agronomy, Anhui Agricultural University, Hefei 230036, China
[c] Department of Agronomy, University of Agriculture Faisalabad, Pakistan
[d] Department of Botanical and Environmental Sciences, Guru Nanak Dev University, Amritsar 143005, Punjab, India
[e] National Maize Key Laboratory, Department of Crop Biotechnology, School of Life Sciences, Hefei 230036, China

ARTICLE INFO

Keywords:
Heavy metals
Pesticide
ROS
Lipid peroxidation
Osmo-protection
EBL

ABSTRACT

Industrialization and urbanization have posed serious threats to the environment. Excessive release of heavy metals from industrial effluents and overuse of pesticides in modern agriculture are limiting crop production by polluting environment and deteriorating food quality. Sustaining food quality under heavy metals and pesticide stress is crucial to meet the increasing demands for food. 24-Epibrassinolide (EBL), a ubiquitously occurring plant growth hormone shows great potential to alleviate heavy metals and pesticide stress in plants. This review sums up the potential role of EBL in ameliorating heavy metals and pesticide toxicity in plants extensively. EBL application increases plant's overall growth, biomass accumulation and photosynthetic efficiency by the modulation of numerous biochemical and physiological processes under heavy metals and pesticide stress. In addition, EBL scavenges reactive oxygen species (ROS) by triggering the production of antioxidant enzymes such as SOD, CAT, POX etc. EBL also induces the production of proline and soluble proteins that helps in maintaining osmotic potential and osmo-protection under both heavy metals and pesticide stress. At the end, future needs of research about the application of 24-epibrassinolide have also been discussed.

1. Introduction

Brassinosteroids (BRs), as endogenous plant growth regulators (PGRs) are considered an important family of steroidal compounds which are necessary in plant's growth and development (Mandava et al., 1981). Many studies have demonstrated positive effects of BRs on growth in different plant species such as *Zea mays* (Mori, 1980), *Vigna radiata*, *Pisum sativum* and *Vigna angularis* (Gregory and Mandava, 1982; Mandava, 1988; Yopp et al., 1981). BRs not only improve the growth and yield of numerous crop plants but also enhance the resistance against several abiotic stresses including pesticides and heavy metal stress (Ali et al., 2008; Janeczko et al., 2005; Xia et al., 2009).

24-Epibrassinolide (EBL), an important brassinosteroid has marvelous characteristics in mediating the biotic and abiotic stresses (Anuradha and Rao, 2007; Sharma et al., 2015). EBL is poly hydroxylated steroidal compound that plays imperative role in regulation of an array of physiological and developmental processes including seed germination, growth stimulation, reproduction and senescence (Clouse and Sasse, 1998). In some studies, applied EBL regulated the growth of apical meristems in potato (*Solanum tuberosum*) tubers (Meudt et al., 1983), accelerated cell division rate in isolated protoplasts of *Petunia hybrid* (Oh and Clouse, 1998), and improved cell division and leaf expansion in *Arabidopsis thaliana* (Zhiponova et al., 2013). EBL application accelerated the plant growth, improved physiological activities and induced alkaloids production in different morphological parts of *Catharanthus roseus* L. (Alam et al., 2016). Exogenously applied 24-epibrassinolide has also been reported to accelerate the ripening process in grapes (*Vitis vinifera*) and promoted the secondary metabolism along with accumulation of flavonoids and anthocyanins (Xi et al., 2013). EBL application in grapes enhanced the soluble sugars; modulated and controlled the sugar unloading in grape berries (Xu et al., 2015). Cell wall space acidification is another influencing factor under the application of 24-epibrassinolide during growth stimulation. Although actual mechanism of EBL action on cell division is still unclear, it is thought that EBL induces the $CycD_3$ transcription that is most probably involved in cell division (Hu et al., 2000). Understanding of molecular mechanism under brassinosteroids action is still in its infancy but few years back, BR-receptor gene for leucine-rich protein (BRII) has been

* Corresponding author.
E-mail address: bs_tahir786@yahoo.com (B. Shahzad).

http://dx.doi.org/10.1016/j.ecoenv.2017.09.066
Received 14 June 2017; Received in revised form 20 September 2017; Accepted 26 September 2017
0147-6513/

identified in *Arabidopsis thaliana* which could lead to understand the undergone mechanism of brassinosteroids on cell division (Li and Chory, 1997). In several documented studies, exogenously applied EBL aided in the regulation of source/sink relationship (Xu et al., 2015). Application of EBL diminished the oxidative degradation in cellular organelles and reduction in malondialdehyde (MDA) contents by modulating antioxidant production (Zhao et al., 1990).

Heavy metals and pesticides (herbicides, fungicides, insecticides) application in modern agriculture are serious environmental contaminants due to the industrialization and their over-use (Anjum et al., 2017; Shah et al., 2016; Shahzad et al., 2016b). Industrialization and urbanization resulted in transfer of heavy metals from different mines to soils, thus reducing agricultural productivity. Heavy metals such as cadmium (Cd), arsenic (As), nickel (Ni), zinc (Zn), chromium (Cr) and aluminum (Al) reduce plant growth and development by inducing a number of metabolic alterations in plants (Anjum et al., 2016a, 2017). Although Al is not a heavy metal, it is potentially a toxic metal having serious concerns regarding plant growth. Increasing levels of heavy metals and pesticides in the environment influence the various physiological and morphological process in plants and cause severe damage to cell organelles and reduce overall crop productivity. Effects of 24-epibrassinolide are not limited to growth and development but it is vital to protect the plants from the detrimental effects of abiotic stresses. Several studies showed the protecting role of EBL in plants under high and low temperature stress (Singh and Shono, 2005), salt stress (Dalio et al., 2011; Divi et al., 2010; Shahid et al., 2015) and drought stress (Vardhini and Rao, 2003). This article attempts to review the existing literature and provides brief and concise information about mediating role of 24-epibrassinolide in plants under heavy metals and pesticide stress (Fig. 1).

2. Heavy metal stress

Heavy metals are considered as a serious environmental contaminants due to the rapid dependence on industry and urbanization (Shah et al., 2016; Shahzad et al., 2016a). Increasing levels of heavy metals in plant's vicinity have various detrimental effects on physiological and biochemical processes within plants (Shahzad et al., 2016b). Some heavy metals cause toxicity in plants due to the binding of metal ions to sulfhydryl groups (-SH) in proteins which eventually leads to inhibition of their activity or disruption of enzyme structures (Hall, 2002).

A rather frequent and common effect of heavy metal stress is the production of reactive oxygen species (ROS), including radicals of superoxide, peroxide and hydroxyl ion in many plant species (Marschner, 1995). ROS disrupts membranes and other macromolecules through lipid peroxidation. However, plants are equipped with an integral enzymatic and non-enzymatic antioxidant production system to scavenge

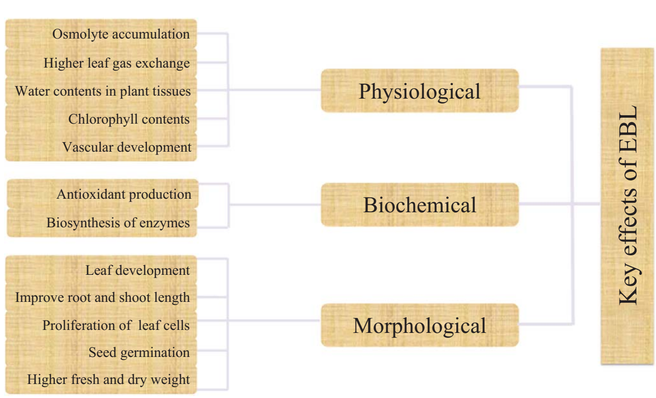

Fig. 1. Key effects of 24-epibrassinolide (EBL) under heavy metal and pesticide stress in plants.

ROS (Salin, 1988), hence plant phyto-hormones such as EBL can regulate antioxidant production under heavy metal stress (Kapoor et al., 2014; Sharma et al., 2011a, 2011b; Ramakrishna and Rao, 2012; Sharma and Bhardwaj, 2007; Özdemir et al., 2004). Application of EBL affects cell permeability, uptake of heavy metals and their absorption by acting at electrical properties of membranes and enzyme activities. Furthermore, mitigation of heavy metal toxicity is associated with the production of soluble proteins and nucleic acids due to the higher activity of ATPase enzyme (Ashraf and Foolad, 2007; Choudhary et al., 2011; Madhan et al., 2014; Ramakrishna and Rao, 2012). EBL attaches with the membrane proteins and scavenges ROS generated under heavy metal toxicity and thereby eliminates the chances of lipid peroxidation (Cao et al., 2005). While binding to the membrane sites, it also enhances enzymatic and metabolic activities and detoxifies heavy metal toxicity in plants. Khripach et al. (1996) confirmed that EBL application aided in the reduction of metal uptake and regulated heavy metal toxicity in radish (*Raphanus sativus*), barley (*Hordeum vulgare*), tomato (*Solanum lycopersicon*) and sugar beet (*Beta vulgaris*). Bajguz (2000) discovered that exogenously applied EBL in the range of 10^{-6}–10^{-4} M showed significant blockage of heavy metals in algal cells. Here, we have tried to describe several studies undergone in finding comprehensive physiological, morphological, and biochemical upregulation of EBL in different plant species under different heavy metals stress. Effects of EBL on osmolyte accumulation and physiological processes are summarized in Table 1 and Table 2.

2.1. Cadmium stress

Cadmium (Cd) is a transition element with atomic weight of 112.411 g, belongs to group 12 in periodic table and it has 2 valence electrons that make it highly reactive in nature. Cadmium is a non-essential element for living organisms and is extremely hazardous even in traces. It is easily taken up by plants and affects diverse morphological, structural, biochemical and physiological attributes in plants even at very small amounts (Anjum et al., 2015, 2016c, 2016d; Ekmekci et al., 2008; Maksimović et al., 2007; Xu et al., 2015). Studies showed that Cd inhibits photosynthetic process by limiting the use of ATP and NADPH in the Calvin cycle (Vassilev and Yordanov, 1997). It further induces the production and formation of radicals of hydroxyl and hydrogen peroxide as well as superoxide anions severely damaging the membranes through peroxidation that ultimately results in cell death (Cho and Seo, 2005; Khan et al., 2007). Liu et al. (2007) reported that Cd and or/As treatment in wheat enhanced the ROS production which further stimulated plant defense system. In another study, translational analysis confirmed that cadmium increased the level of mitogen-activated protein (MAP) kinase which interprets that it was possibly activated by ROS production (Jonak et al., 2004). Milone et al. (2003) revealed that morphological parameters and activity of some antioxidant enzymes like superoxide dismutase (SOD) was decreased proportionally with an increase in Cd level. Likewise, Mahmood et al. (2009) confirmed that cadmium toxicity caused oxidative stress in plants and reduced the growth and altered membrane permeability while inducing the production of reactive oxygen species at subcellular level. Shakirova et al. (2016) reported that Cd-stress stimulated the induction of MDA contents and increased the electrolyte leakage by inducing oxidative stress in wheat (*Triticum aestivum* L.).

Different studies suggest that application of 24-epibrassinolide can ameliorate toxic effects of cadmium. In *Raphanus sativus* L. seedlings, Anuradha and Rao (2007) unveiled that EBL application ameliorated the toxic effects of cadmium by enhancing the level of free proline. They further observed that antioxidant enzymes activities such as catalase (CAT), superoxide dismutase (SOD), ascorbate peroxidase (APX) and guaiacol peroxidase (GPOD) were also increased in the seedlings under cadmium stress due to the 24-epibrassinolide application. Kapoor et al. (2014) disclosed that applied 24-epibarssinolide improved the