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Gibberellic Acid Application and Wheat Production

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ABSTRACT

Gibberellic acid (GA_3) is known as important plant growth regulators which are also considered to induce various physiological responses in plants, which is unduly suited for improving and stimulating, photosynthetic activity, and plant growth. Gibberellic acid, a tetracyclic di-terpenoid compound which is known as a plant hormone stimulating plant growth and development. Gibberellins may have an important function in different metabolic pathways influencing several characteristics, such as nitrogen redistribution, nitrogen metabolism, translocation of assimilates, chlorophyll production and degradation. This review article aims to provide an overview of the effects of gibberellic acid on yield and yield components of wheat and survey of different mechanisms of action of gibberellic acid in different plants. The keywords searches for gibberellic acid, wheat, root growth, gibberellin, plant hormone, and plant growth were performed by using PubMed, Google scholar, Scopus, and Web of Science.

Keywords: Benzyl adenine, Gibberellic acid, Grain protein, Irrigation, Salicylic acid, Superoxide dismutase, Wheat.

INTRODUCTION

It has been reported that gibberellic acid (GA_3) has significant ability to reduce the adverse impacts of salinity by promoting accumulation of osmolytes, antioxidant enzyme activity, and boosting vigor (Shahrajabian *et al*., 2011; Seo *et al*., 2019). GA_3 can significantly promote the stimulation of various non-enzymatic and enzymatic antioxidants, and the accumulation of osmolytes in plants (Jaleel *et al*., 2007; Misratia *et al*., 2015; Shahrajabian *et al*., 2021). The most important functions of GAs in plants are breaking of seed dormancy, seed germination and seedling growth, promotion of cell division and stem elongation, induction of fruit enlargement, regulation of sex expression in some plants, promotion of flowering in long day plants, prevention of genetic dwarfism, and tolerance to chilling (Gupta and Chakrabarty, 2013; Shahrajabian *et al*., 2023). Its application can boost the development of plant by revealing the fact that they improve the amino acid concentration in embryo and promote the syntheses of hydrolytic enzyme needed for digestion of endospermic starch when renew growth at seed germination (Soleymani *et al*., 2010; Soleymani *et al*., 2011; Ghanbary *et al*., 2020; Sun and Shahrajabian, 2023; Sun *et al.*, 2023). GA signaling positively regulates the resistance of rice to saline-alkali, and promotes resistance to saline-alkali stress by increasing the uptake of ammonium in rice (Li *et al*., 2024). Bekaardt *et al*. (2004) reported that application of GA_3 can result in the highest seed germination in guayule, and Araujo *et al*. (2009) also showed that GA_3 application can increase the emergence of seeds of Jua tree. Its application can reduce the negative impacts of phytotoxic impacts, as it can restored the mobilization of starch and protein reserves from the endosperm to seedling roots during germination of barley plants (Amri *et al*., 2016; Pan *et al*., 2017). GA_3 can increase plant height, enhance yield, increase in chlorophyll contents, boost antioxidant enzymes, enhance P, K, Fe, and Mn in plants, reduce reactive oxygen species (ROS) production, and decrease in Zn concentrations (Araujo *et al*., 2009; Rodrigues *et al*., 2012; Liu *et al*., 2013; Uslu *et al*., 2013; Gokdere and Ates, 2014; Goel *et al*., 2023). It has been reported that the foliar application of GA can significantly influence both wheat physiology and morphology, and foliar application of GA increased wheat growth and nutritional quality with positive impact on wheat irrespective of nanoparticles (NPs) combinations or alone supply (Al-Huqail *et al*., 2023). In many experiments, it has been reported that GA_3 treatment can increase stem elongation through changing the orientation of cellulose microfibrils, regulate cambial cell division, promote xylem differentiation, and lead to formation of secondary xylem fibers (Sauter and Kende, 1993; Bjorklund *et al*., 2007; Hamayun *et al*., 2010; Yazdpour *et al*., 2012; Cuiying *et al*., 2013; Ogbaji *et al*., 2013; Wang *et al*., 2015). GA_3 application can delay ripening stage and increase shelf life of sweet cherry (Kondo and Danjo, 2001), and it can also improve and stimulate both bolting and flowering stage (Ingram *et al*., 1986; Singh and Usha, 2003; Hara *et al*., 2012; Peng *et al*., 2014; Zhang *et al*., 2018; Jung *et al*. 2020). This article aimed to assess the impacts of different plant growth regulators and irrigation treatments on different growth and development of winter wheat. The goal of this article is to study the impacts of gibberellic acid on different plants, especially wheat by considering different mechanism of action. In this manuscript, the presented information gathered from randomized control experiments, review articles, and analytical studies and observations which were obtained from PubMed, Science Direct, Scopus, and Google Scholar. The keywords used were the common and Latin names of different agronomical plants, wheat, gibberellic acid, gibberellin, reactive oxygen species, plant hormone, and plant growth regulator.

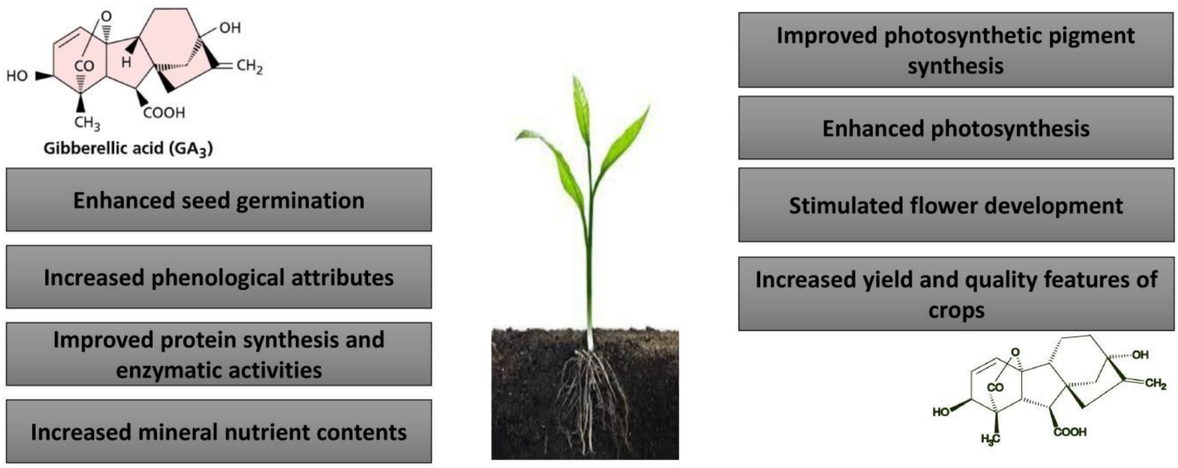

Figure 1. Effects of gibberellic acid on growth, photosynthesis and antioxidant defence of crops.

Gibberellic acid (GA_3) and the Mechanism of Action

GA_3 is a biologically form of Gibberellins (GAs) (O'Neill et al., 2000; Zhou et al., 2009), which can promote cell elongation, and increase cell numbers, and the are the main parameter involved in stem elongation (Srivastava and Handa, 2005; Kato *et al*., 2011; Shen *et al*., 2020). GA_3 is important in reducing abiotic stress-induced perturbations in different plants by modulating various physio-biochemical and molecular processes, and around 140 different GAs can be discovered in higher plants and gibberellin-producing fungi, and most of them serve as precursors or catabolites, with only a few having independent biological characteristics (El-Tohamy *et al*., 2023). GA are essential plant regulators for different plant development processes, such as seed germination, leaf extension, stem elongation, flowering induction, and pollen maturation, and mutant plants which are deficient in GA have a dwarf phenotype and late flowering, treating the plants with GA restores normal growth (Cornea-Cipcigan *et al*., 2020; Shahzad *et al*., 2021; Elahi *et al*., 2023). GA_3 content in the stems is the key parameter for the change in internode diameter and length of soybean internodes in response to shading (Zhang *et al*., 2011; Hedden and Thomas, 2012; Wu *et al*., 2017; Sun *et al*., 2021a,b,c). GA_3 offers an ideal molecule platform for chemical modifications, as it is a tetracyclic diterpenoid compound including two hydroxyl groups, a lactone ring, and a carboxyl group (Phuoc *et al.*, 2008), and GA_3 derivatives featuring diverse structures could show various biological roles from parent molecule GA_3 (Mander, 2003; Murase *et al.*, 2008), for instance, 7-homo-GA_3 and 16,17-dihydro-GA_5 inhibited stem elongation, while 16,17-dichloromethano-dihydro-GA_3 has an inhibitory impact on both stem elongation and flowering of many plants (Berger *et al.*, 1982; Mander *et al.*, 1998). Moreover, some gibberellin derivatives characterized by an α,β-unsaturated ketone moiety even revealed anti-tumor characteristics (Chen *et al.*, 2009; Zhang *et al.*, 2012). The functional groups in the ring A of GA_3 were quite sensitive under many reaction conditions (Kirkwood *et al.*, 1980; Oh *et al.*, 2012).

The increase in GA_3 and GA_7 levels caused by the interaction of high temperature and low light which can promote the elongation of soybean hypocotyls (Bawa *et al.*, 2020; Zhang *et al.*, 2020). It can also increase the length of internodes and the overall height of plants and decreases mechanical strength (Beal et al., 1996; Yuan and Yang, 2007; Martinez-Garcia *et al.*, 2010). After application of GA_3 to soybean the contents of jasmonic acid, GA_1, and GA_4 were shown to have increased, while the abscisic acid and salicylic acid contents decreased (Ingram *et al.*, 1986; Martin *et al.*, 1996; Hamayun *et al.*, 2010; Larson *et al.*, 2023). GA_3 usage is an effectual way to change plant height, and the current researches in different parts of the world are about the usage of GA_3 involve the spraying of leaves or soaking of seeds (Shan *et al.*, 2021; Shahrajabian and Sun, 2023a,b,c). Zalnierius et al. (2022) reported that the exogenous GA_3 application result in incomplete seed development, and a consequent reduce in variability and germination, and the maximum GA_3 dose resulted in significantly reduction in propagation of Sosnowsky' hogweed through seeds in the field, which shows the importance of GA_3 as a promising approach to the control of the spread of some weed species. GA_3 application can increase and its concentration in stems is the major parameter for the change in internode diameter and length of soybean (Zhang *et al.*, 2011; Zhang *et al.*, 2020; Bawa *et al.*, 2020). The usage of GA3 is effective in increasing seedling growth and length (Shahrajabian *et al.*, 2021; Sharajabian and Sun, 2023g,h,I; Sun and Shahrajabian, 2024; Sun *et al.*, 2024). It has been reported that the treatment of dwarf varieties of rye with GAs increased the activity of α-amylase in the germinating caryopses (Zwar and Chandler, 1995), and treating seeds with GA_3 increased α-amylase expression through binding of a transcription factor to the gene, which activated it (Wang *et al.*, 2016). Dwarf rye varieties are capable to synthesize GA_3 under certain conditions, and the normal growth of these varieties can be restored by exposure to exogenous GA_3 (Pavlista *et al.*, 2014; Shahrajabian and Sun, 2023d,e,f). Skalicky *et al.* (2020) reported that usage of GA_3 to the seeds had no impact on the transition of the growing point to the double-ridge generative stage of wheat plants, and the priming effects of GA_3 on seeds of common wheat varieties with various vernalization and photoperiod requirements as it influenced the transition from vegetative to generative stage.

It is also reported that GA_3 can help in the stimulation of various non-enzymatic and enzymatic antioxidants and the accumulation of osmolytes in plants, and the usage of exogenous GA_3 proliferates plant development by leading to the intensification of amino acid synthesis of hydrolytic enzymes as prerequisite for the breakdown of endospermic starch when plant seeds renovate development at the seed propagation stage (Jaleel *et al*., 2007; Tuna *et al*., 2008; Moumita *et al*., 2019). The modified GA_3 derivatives characterized by amide groups could provide wonderful bioactivities to the target components, and the synthesis of a series of novel C3-OH substituted GA_3 derivatives bearing an amide moiety (Zhu *et al*., 2012; Zong *et al*., 2014; Gao *et al*., 2016). It has been reported that gibberellic acid leads to cell enlargement and division, produces new tissues, increases protein biosynthesis, and promotes the absorption of nutrients and water, and it is an effective method in improving grape cultivar berries, which could be also used in wide range orchards (Abu-Zahra and Salameh, 2012; Dimovska *et al*., 2014; Abu-Zinada, 2015; Alshallash *et al*., 2023). For many species with physiological dormancy, it is usually possible to preemptively break seed dormancy by adding GA to the seed, which increases the endogenous levels of GA relative to ABA (Xu *et al*., 2017; Larson *et al*., 2023), and the addition of GA to the seed may also promote the cell expansion, activation of enzymes, and the mobilization of stored reserves, which collectivelly facilitate the transition from dormancy to germination (Gupta and Chakrabarty, 2013; Gonzalez-Lopez *et al*., 2014; Shu *et al*., 2018). Mimi *et al*. (2023) reported that gibberellins act to overcome dormancy and increase the germination rate of seeds of several species, including genus *Annona*, and GA_3 concentrations (500 and 1000 mg L^{-1}) led to increases of 25%, and 20%, respectively, in the germination rate, intensification of lipid degradation in seeds with primary root emission, and a decrease in sugar concentration until the 5th days. In another experiment the application of 10^{-4} M GA_3 exceeded the acceptable threshold for use in hydroponics production systems of lettuce, and GA_3 stimulated plant growth and increased the yield, such as leaf expansion, stomatal conductance, biomass accumulation, nitrogen use efficiency, and water use efficiency (Miceli *et al*., 2019). Foliar application of gibberellic acid negatively influenced vegetative growth of kenaf, and exogenous gibberellic acid delayed flower and bud initiation in kenaf cultivars (Muniandi *et al*., 2018). Gibberellins biosynthesis pathway is presented in Figure 2.

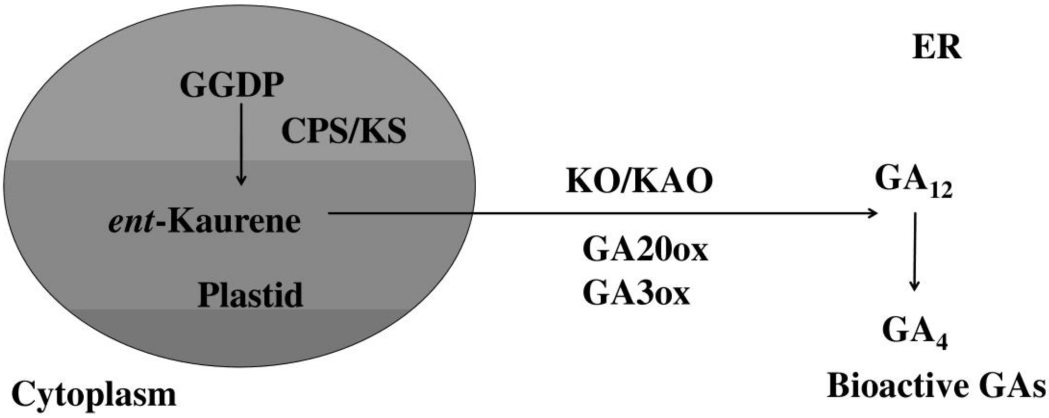

Figure 2. Gibberellins biosynthesis pathway; residing in three different cellular compartments (cytoplasm, endoplasmic reticulum, and plastid). *ent*-CDP: ent-copalyl diphosphate; GGDP: geranylgeranyl diphosphate; KS: *ent*-kaurene synthase; CPS: *ent*-copalyl diphosphate synthase; KAO: *ent*-kaurenoic acid oxidase, KO: *ent*-kaurene oxidase.

Gibberellic acid (GA_3) and Wheat Production

Gibberellic acid (GA_3) are known as important plant growth regulators which are also considered to induce various physiological responses in plants (Azizi *et al.*, 2023), which is unduly suited for improving and stimulating, photosynthetic activity, and plant growth (Shayanfar *et al.*, 2011; Soleymani *et al.*, 2013; Soleymani and Shahrajabia, 2017). GA_3 is a biologically active form of gibberellins (GAs) (Srivastava and Handa, 2005), and GAs promote cell numbers, and increase cell elongation, which has shown in importance in stem elongation (Hedden and Thomas, 2012; Shen *et al.*, 2020). GAs can stimulate root and stem elongation, flowering, leaf expansion, seed germination, fruit senescence, and seed dormancy (Hooley, 1994; Kato *et al.*, 2011; Hedden and Sponsel, 2015; Cui *et al.*, 2023), as they can lead to better cell division, and cell elongation during growth, and improve the expression of hydrolytic enzymes which have function in the conversion of starch into sugar (Akiyama and Suzuki, 1980; Broumand *et al.*, 2010; Khoshkharam *et al.*, 2010; Riaziat *et al.*, 2012; Sayed *et al.*, 2020; Aliahmadi *et al.*, 2021). The application of gibberellic acid can cause a rapid stimulation of growth of wheat plants, reaching a maximum withing four weeks, and it can also cause yellowing of the herbage and stem elongation up to the first mowing, six weeks after application (Scott, 1959; Horre *et al*., 1989; Hartung *et al*., 2010; Matzer *et al*., 2010; Rebetzke *et al*., 2012; Gupta and Chakrabarty, 2013).

Pfleger *et al*. (2011) reported that gibberellic acid 30x had significant influence on wheat seedling development, and the wheat growth bio assay can be appropriate tool for further experiments on homeopathic dilutions of gibberellic acid. The positive increase of grains of winter wheat was also reported after application of gibberellic acid (10^{-30}) (Endler *et al*., 2015). Priming with GA_3 (150 mgL^{-1}) was very effective in increasing salicylic acid concentration in wheat cultivars under salt stress, and its treatment decreased leaf free putrescine and spermidine concentrations in the plants of wheat cultivars (Iqbal and Ashraf, 2013). Foliar application of GA increased wheat growth and nutritional quality when exposed to nanoparticles (NPs), minimized the oxidative stress, enhanced the growth of NPs-stressed wheat, and showed positive impacts on wheat irrespective of NPs combinations or alone supply (Hou *et al*., 2008; Al-Huail *et al*., 2023). GA increased the wheat growth at all doses of TiO_2 NPs, increased the photosynthetic pigments and antioxidant enzyme activities at all doses of TiO_2 NPs, and boosted the nutritional values of wheat grains under TiO_2 NPs (Alharby *et al*., 2021; Alybayev *et al*., 2024). Exogenous application of GA increased seed germination, and plant growth traits undr Ni stress, it could lowered the Ni fixation inside the root cell wall and hemicellulose, and regulated the antioxidant activities, glyoxalase systems to scavenge the ROS, and modulated the phytochelatins and antioxidant-related gene expression level for sequestration and efflux (Bossen *et al*., 1991; Mathur *et al*., 1992; Bhat *et al*., 2023). GAs are synthesized by the action of terpene cyclases, cytochrome P450 mono-oxygenases and 2-oxoglutarate-dependent dioxygenases localized, respectively, in plastids, cytosol, and the endomembrane system, and GAs are synthesized in actively growing organs on plants like roots, leaves, fruits, and developing seeds (Akiyama and Suzuki, 1981; Saluja *et al*., 1987; Saluja *et al*., 1989). Chattopadhyay *et al*. (1994) showed that GA_3 induced elongation of wheat coleoptile sections and the effect of GA was reduec to 1/4 when the endogenous methyleneoxinodle (MeOx), an oxidation product of IAA, was made unavailable to GA_3 during its action.

CONCLUSION

Plant growth regulators are synthetic or natural substances which influence the growth and development of many crops, especially wheat. They control one or more specific biochemical and physiological characteristics possibly by their effects on enzyme and gene activities. In fact, the organic chemical component other than nutrients which are active in low concentration in inhibiting, promoting or modifying growth and development should be called growth regulators. Plant growth regulator which comes through photosynthesis supplies and respiration can control the growth and development of plant. Phytohormones are organic components produced naturally by the plants in low concentration with very low concentration. GAs are the second noticeable growth hormones found in plants, and they are natural or endogenous hormones which can be produced by some tissues in plants. The physiological processes like growth and development of the plant, flower differentiation, enhancement of the fruit color, tissue growth, fruit ripening, etc., are controlled by the suitable applications of GAs. GAs are synthesized in actively growing organs by the action of terpene cyclases, cytochrome P450 mono-oxygenases and 2-oxoglutarate-dependent dioxygenases localized, respectively in the cytosol, the endormembrane, and in plastids. In wheat production, exogenous application of GA_3 can promote seed germination and subsequent seedling growth under different stresses. Its application can ensure the growth of wheat plants.

Disclosure statement

The authors declare that they do not have any conflict of interest

Author contributions

All authors have contributed equally to this manuscript.

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