https://doi.org/10.33472/AFJBS.6.5.2024. 2790-2810

AfricanJournalofBiological Sciences

Gibberellic acid: A Multifaceted Modulator for Plant Growth, Development and Stress Mitigation

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Article History
Volume 6, Issue 5, 2024
Received: 01 May 2024
Accepted: 09 May 2024
doi:*10.33472/AFJBS.6.5.2024. 2790-2810*

Abstract

Gibberellic acid (GA) serves as a multifaceted modulator with profound implications for plant growth, development, and stress mitigation in fruit crops. Through its multifaceted actions, GA promotes cell elongation, seed germination, and flowering induction, enhancing growth and reproductive success. Additionally, GA aids in stress mitigation by enhancing plant resilience to adverse environmental conditions such as drought, salinity, and extreme temperatures. Its strategic application not only improves fruit yield but also enhances quality attributes, meeting consumer preferences for premium produce. Hence, GA emerges as a valuable tool for optimizing fruit crop production, enhancing productivity, resilience, and market competitiveness in sustainable horticultural practices. Overall, this review effectively communicates the essential role of GA as a versatile tool, where the strategic application of GA offers opportunities to improve fruit quality attributes, including size, uniformity, and nutritional content, meeting consumer preferences for high-quality produce.

Keywords: *gibberellic acid, multifaceted, plant growth hormone, and stress mitigation*

1. Introduction:

Plants encounter a wide range of stresses during their growth and development phase, broadly divided into abiotic or biotic stresses. Abiotic stresses, such as limited water availability, salinity, and fluctuating temperatures,*etc.*serve as primary environmental constraints that adversely impact the physical, physiological, and biochemical processes in plants, impacting the overall production (Zhu 2016; Shah *et al*., 2021,2022^{a,b}).Biotic and abiotic stresses impact the metabolic processes, physiological structure, and productivity of plants (Temgire*et al*., 2023).

Apart from these inherited mechanisms, the application of plant growth regulators (PGRs) has become a widespread method to enhance the yield and quality of both horticultural and agricultural crop production, besides alleviating the impact of abiotic stresses occurring to the plants (Shah *et al.*,2023). PGRs work as tiny chemical messenger molecules, influencing the growth, physiological, and biochemical characteristics of plants in addition to the genotypic functions of plants (Rademachar,2015; Sabagh*et al.*,2022).

Among all the PGRs, Gibberellic acid, a significant phytohormone, playsa key role in adjusting and controlling numerous growth and developmental processes. Gibberellins, commonly referred to as gibberellic acid (GA), were first discovered by Western scientists in the 1950s. However, In Asia, awareness related to GAs began with the outbreak of a fungal disease named bakanae disease, or foolish seedlings in rice (Gupta and Chakrabarty 2013; Taiz *et al.*,2015). Even so, the first identified gibberellic acid (GA_1) was discovered inrunner bean seeds in the year 1958 (Schwechheimer, 2008). GAs plays a crucial role inthe stimulation of growth and developmental processes in different agricultural and horticultural crops, encompassing activities like cell expansion, cell division, seed germination, utilization of endosperm storage reserves, elongation of internodes, progression to flowering, sexual expression, and fruit development (Othman and Leskovar, 2022).Furthermore, the application of GA_3prolongs the post-harvest lifespan of fruits, vegetables, and flowers by retarding senescence, impeding chlorophyll breakdown, and enhancing the antioxidant system (Kuchi *et al*.,2017). besides, mitigating the effects of environmental stresses (Elahi *et al*.,2022).GA_3can also interact with other plant growth regulators, influencing metabolic processes through both synergistic and antagonistic mechanisms (Abbas *et al.*,2022).GA_3, as a natural growth promoter, enhance nutrient absorption and utilization efficiency while also improving tolerance to both biotic and abiotic stresses (Chitra *et al*., 2022). Considering the varied and significant roles of gibberellic acid throughout the plant life cycle, the current article seeks to provide a timely review of biosynthesis, signaling pathways, and the impact of GAs on the growth and development of plants.

1. Biogenic Synthesis:

Gibberellins occur naturally in several plant parts, such as germinating and developing seeds, young leaves, and internodes**.** However, the synthesis and breakdown of gibberellin (GA) hormones are intricately regulated, under strict genetic control maintaining the even distribution and synthesis of hormones in a tissue-specific and developmentally mediated manner (Taiz *et al.*,2015). The biosynthesis of GA starts with the synthesis of geranyl-geranyl diphosphate (GGPP) from isopentenyl diphosphate (IPP), a central 5-carbon intermediate for numerous isoprenoids and terpenoid compounds(Kasahara *et al.*,2002; Hedden and Thomas, 2012) (Fig. 1)

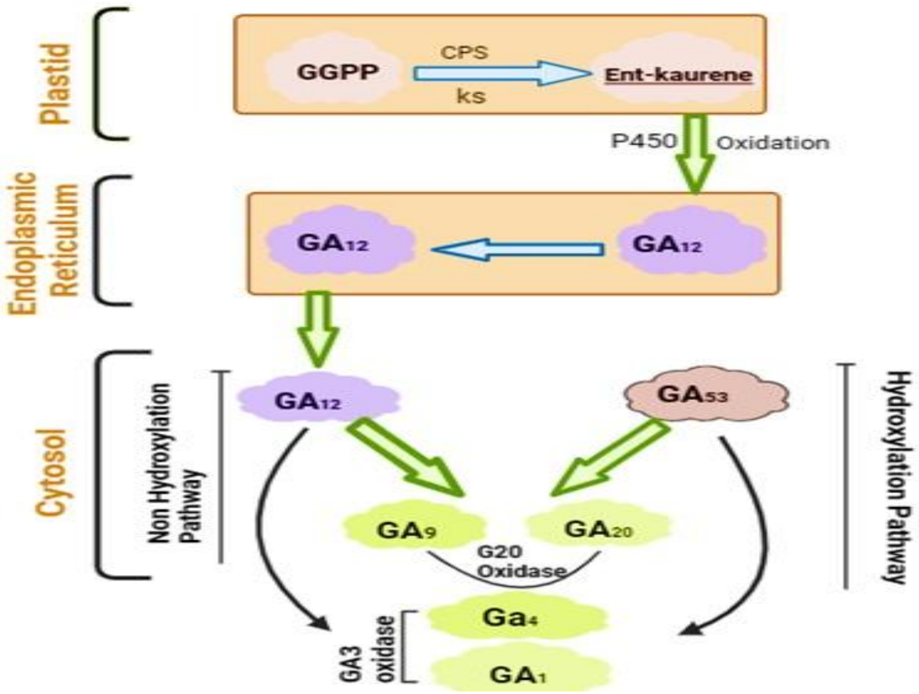

Fig. 1. Biosynthesis mechanism of GA_3in plants

The biosynthetic pathway of gibberellin (GA) can be classified into three distinct phases i.e. initial phase occurs in plastid where GGPP is converted into ent-kaurene, catalyzed in the presence of two enzymes: ent-copalyl diphosphate synthase (CPS) and ent-kaurene synthase (KS) (Van *etal.*,2007; Taiz *et al.* 2015).Whereas, the second phase occurs in the endoplasmic reticulum (ER), where ent-kaurene undergoes oxidation to GA_{12}-aldehyde, facilitated by cytochrome P450 monooxygenases, which include ent-kaurene oxidase (KO).Further, GA_{12}-aldehyde undergoes conversion to GA_{12} (Hedden *etal.*,2002; Davidson *et al.* 2006). The third phase is carried in cytosol where GA_{12} and GA_{53} act as precursors for both the non-13-hydroxylation pathway and the 13-hydroxylation pathway. This process leads to the formation of GA_9 and GA_{20}, respectively, catalyzed by GA_{20}-oxidase (GA_{20}ox). Finally, thelast phase in the biosynthesis process involves the 3β-hydroxylation of GA_9 and GA_{20}, facilitated by GA_3-oxidase (GA_3ox), resulting in the formation of bioactive GAs in plants, namely GA_4 and GA_1 (Cerezo *et al.*,2018; Hedden 2020).Thereafter, the bioactive substances GA_4 and GA_1 undergo inactivation through the action of GA_2-oxidase (GA_2ox). During the complete biosynthesis process seven genes, namely GA_2ox_1, GA_2ox_2, GA_2ox_3, GA_2ox_4, GA_2ox_6, GA_2ox_7, and GA_2ox_8, encode for GA_2-oxidase enzyme that plays a crucial role in regulating the concentration of gibberellic acids (GA's) throughout plant growth and development, while also responding to unfavourable environmental conditions (Li *et al.*,2019).

2. Gibberellic acidSignalling:

Gibberellins control various aspects of plant physiology by influencing both transcriptional and post-transcriptional alterations within the cells (Schwechheimer,2008). The signalling process of Gibberellins (GA's) in plants encompasses a delicate equilibrium between the gene expression controlling GA production, the presence of GA receptors, and the concentration of enzymes responsible for deactivating active GA (Sun and Gubler,2004; Daviere and Achard,2013). One of the most essentialparts in GA signalling is the GA receptor, *i.e*., GID1 (gibberellin insensitive., dwarf 1) is a soluble protein found in both the cytosol and nucleus, featuring a C-terminal domain responsible for binding to Gibberellins (Griffiths *et al.*,2006; Ueguchi-Tanaka *etal*.,2007). Whereas DELLA proteins serve as inhibitors of Gibberellinsignalling in numerous plants, controlling and limiting different plant functions (Yoshida *et al*.,2014). such as seed vigor, plant height, plant biomass, the antioxidant system, and photosynthesis of plants under fluctuating environmental conditions(Ramesh and Kumar, 2006;Hamayun*et al*., 2010 and Saleem *et al*. 2020). Gibberellins (GAs) are a significant group of plant hormones that trigger numerous metabolic processes (Negi and Sharma, 2022).

4. Effect of Gibberellins on abiotic stresses.

4.1 Gibberellic acid for salinity stress mitigation

Salinity poses a significant risk to contemporary agriculture by hindering and damaging the growth and development of plants (Isayenkov and Maathuis, 2019). Salinity is a significant abiotic stress affecting approximately 6% of the land surface area (Parihar *et al*., 2015). The distribution of minerals, membrane stability, and permeability, carbon and nitrogen metabolism, and chlorophyll production are all disrupted by salinity stress (Hakkem*et al*., 2012). It has been reported, that GAs can reduce the negative impacts of salinity by improving plant production through increasing chlorophyll content, nitrate reductase activity, carbonic anhydrase activity, and nitrogen-use efficiency (Criado *et al*., 2017).In the presence of higher concentrations of salt stress, GAs increase the germination percentage by enhancing starch reserve transitions and increasing amylase activity in cotyledons (Kaur *et al*., 1998;Macneill*et al*., 2017). Gibberellins provide the ability to the plants to alter their biochemistry and physiological processes when faced with adverse conditions (Franklin, 2008). Plant hormones that are smaller in size and possess low concentration in cells play a crucial function in regulating plant growth processes and responding to stress conditions (Colebrook, 2014).

Further,gibberellins are essential plant growth hormones that enhance a plant's resistance to abiotic stresses. Thereby, contributing to the enhanced antioxidant capabilities of plants in ROS scavenging linked to the enzymes responsible for H_2O_2-detoxification. During photosynthetic cycles, the endogenous form of GA_3 improves the characteristics of photosynthesis, including stomatal conductance, net photosynthesis (PN), photosynthetic oxygen evolution, and carboxylation efficiency. Moreover, during the cell cycle, GA_3can impact the division and enlargement of cell growth in plants experiencing stress. This results in enhanced growth of radicle cells in a meristem, ultimately leading to an increased germination rate and longer root lengths in stress-affected plants.Exogenous application of GA_3 can stimulate the production of SA (salicylic acid), leading to increased levels of SA. This, in turn, enhances the plant's defense response to abiotic challenges in the environment (Emamverdian*et al*., 2020).

Soil salinity poses a significant environmental challenge, hindering the growth and progress of crop plants through various mechanisms including osmotic stress, ionic imbalance, oxidative stress, metabolic disruption, and nutrient deprivation (Isayenkov and Maathuis, 2019; Islam *et al*. 2021). There is substantial evidence indicating that GA_3 shields plant species from harm caused by salt stress by preserving membrane integrity, balancing ion levels, enhancing the activity of antioxidant enzymes, regulating the concentration of compatible solutes, safeguarding photosystems, and stimulating the expression of genes responsive to stress (Shah *et al*.,2023).

Soil salinity greatly hampers the growth, development, and yield of field crops. It also reduces seed emergence and germination rates (Gill,2013; Saade 2016). According to Kaur *et al*., GA_3 when applied at a dose of 6 μM, stimulates improved seedling growth in the presence of salt stress. The exogenous application of GA_3 may lead to the reduction of salt stress by activating specific enzymes involved in RNA and protein synthesis, resulting in various advantages (Bejaoui,1985).

4.2 Gibberellic acid to mitigate water stress

The importance of studying the interaction between horticulture plants and their environment is well recognized, particularly considering the current climate change situation. These plants provide substantial nutritional content and can function as a principal food supply for both developed and developing nations (Manzoor *et al*.,2023). Various factors affect the plant response among which water stress is a significant environmental factor that adversely impacts various plant processes, resulting in decreased crop productivity globally (Kaur and Asthir, 2017; Seleiman*et al*. 2021).

Water stress induces a range of interconnected physiological and biochemical disorders that harm plants by disturbing cellular metabolism and causing cell damage through ionic and oxidative stress. The most significant consequences of water stress involve the gradual or rapid loss of water through stomata, resulting in cell dehydration and eventual cell or tissue death.Water stress triggers a range of physiological, biochemical, and molecular mechanisms in plants, mostly through osmotic stress (Witcombe *et al*., 2008). Research indicates that GA_3 plays an important role in enhancing plant performance during periods of drought or water stress (Li *et al.*,2010; Al-Shasheen and Soh, 2016; Khan *et al.* 2016).

When GA receptors are mutated or when GA activity is inhibited, water loss is decreased through several tactics, such as reducing leaf area, suppressing the production of xylem, or closing stomata (Nir *et al*. 2014).Water stress resulted in a decrease in leaf area by lowering the quantity and size of cells. Application of GA_3 results in enhancement of leaf development via stimulating growth processes. Monosaccharides significantly increased in concentration under water stress, and GA_3 may have further enhanced this accumulation (Alhadi *et al*., 1999).

4.3 Gibberellic acid to mitigate temperature stress

Temperature stress is one of the main issues for plant scientists worldwide because of the frequent variation in climate. Whereas, the fluctuations in temperature caused by global warming serve as significant environmental stimuli. Both high and low temperatures pose a considerable challenge to various physiological, biochemical, and metabolic processes in plants. These include seed germination, seedling growth, photosynthesis, protein integrity, enzyme function, membrane integrity, and cell/tissue viability (Mathur *et al*., 2014; Szymanska *et al*. 2017). Low-temperature stress reduces a plant's capacity for photosynthetic energy and efficiency by changing gas exchange and the synthesis of chloroplast chlorophyll fluorescence (Anwar *et al*., 2018).

The horticultural crops cultivated in tropical and subtropical areas face a serious storage issue due to chilling injury. Chilling stress increases the formation of ROS and the ability of plants to scavenge ROS during and after treatment reflects their resistance and adaptation to low temperatures (Zhao *et al*., 2011). Fruits treated with paclobutrazol (GA biosynthesis inhibitor) experienced a reduction in natural GA_3 content aggravating chilling injury (Ding *et al*., 2015). Plants use growth repression as a key strategy towards abiotic stress tolerance by producing bioactive GA to encourage the breakdown of DELLA (Achard and Genschik, 2009).

Exogenous GA increases stress tolerance by inducing the ubiquitin-proteasome system to degrade DELLA proteins (Achard *et al*.,2009).GA_3 applied exogenously minimized chilling injury by preventing electrolyte leakage, decreasing MDA concentration, raising proline content, and increasing antioxidant enzyme activities which eventually helped to postpone fruit ripening, promote firmness, and extend the shelf life of peach fruit in cold storage (Dagar *et al*., 2012). Nowadays, GA is used to mitigate the symptoms of chilling injury symptoms in horticultural crops and fruits under low-temperature storage (Hu *et al*., 2018).

5. Importance of gibberellic acid for flower and fruit development

5.1 Gibberellic acid in seed emergence

A seed holds a dormant embryo that awaits the right environmental cues to sprout and grow into a plant, thereby completing its life cycle (Bewley, 1997). Seed germination is an important event in the lifecycle of seed plants which is influenced by numerous environmental and internal factors such as light, moisture, temperature, endogenous plant hormones, etc. Gibberellic acid promotes seed germination, whereas abscisic acid (ABA) is responsible for the maintenance of seed dormancy (Kim and Park, 2008; Ravindran and Kumar, 2019).

Gibberellic acid facilitates seed germination by enhancing the proteasome degradation of RGL2 (a DELLA repressor) that inhibits germination (Piskurewicz*et al*., 2008). The influence of gibberellic acid (GA) manifests in two ways: firstly, by enhancing the growth capacity of the embryo, and secondly, by triggering the activation of hydrolytic enzymes (Ogawa *et al*., 2003; Kucera *et al*., 2005; Leubner, 2006). During seed germination, embryonic gibberellic acid (GA) is emitted, initiating the softening of the seed coat by activating gene expression associated with cell expansion and alteration (Finkelstein *et al*., 2008). The findings from the above studies suggest that GA_3 serves as a natural regulator in the complex mechanisms of seed germination by promoting the activity of hydrolytic enzymes essential for overcoming seed dormancy (Shah *et al*., 2023).

5.2 Gibberellic acid for flowering and reproductive morphology

Gibberellins are the plant growth hormones that regulate growth and enhance many developmental processes including leaf and fruit senescence, sex expression, stem elongation, germination, dormancy, flowering, and enzyme induction (Ghosh and Halder, 2018). Gibberellic acid (GA's) plays a crucial role in controlling the onset and progression of flower formation, and they are essential for both female and male reproductive functions in plants (Shah *et al*., 2023). GA is essential for controlling the later stages of stamen development (elongation of filaments, the opening of anthers, and the maturation of pollen) While GA governs the initial development of anthers (Song *et al.*, 2013).

Gibberellic acidcan replace certain specific environmental factors that control flower formation. Application of GA_3 blossoms most of the long day and cold requiring plants. It also enhances flowering in specific long-short-day plants when it is replaced for the long-day requirement. Gibberellin typically boosts flower development in short-day plants under conditions that promote flowering, but its impact tends to be unfavorable when these plants are cultivated under conditions that do not promote flowering (Ghosh and Halder, 2018). The reduced germination rate could be attributed to the absence of embryos in the fruits, resulting in parthenocarpy (Sharma, *et al*., 2022).The application of paclobutrazol through soil drenching to tissue culture plants during the Ambe Bahar season resulted in fruits with the highest weight. This outcome could be attributed to reduced utilization of tree reserves for vegetative growth, potentially eliminating limitations on assimilate availability (Hussain et al., 2021).

During vernalization, gibberellic acid acts as a florigen it is primarily responsible for flowering in fruit crops, even though its inhibitory effects are more prominent than its role in flower induction. Gibberellic acid (GA_3) can serve as a substitute for environmental conditions that promote flowering, especially in long-day plants, and is primarily employed to initiate flowering in these types of plants (Khinchi and Mondal, 2024).GA_3possesses an ability to serve as an alternative to the environmental factors that promote flowering, primarily used to initiate flowering in long-day plants (King *et al*., 2006).

5.3 Gibberellic acid impact on fruit initiation and fruit growth

Gibberellin promotes cell expansion, leading to increased size. Additionally, it retards ripening, allowing fruits more time to mature and consequently grow larger. Fruit development occurs when the ovary of a flower transforms into a fruit after successful pollination and fertilization. Initially, auxins were commonly utilized for fruit sets, but gibberellins are now regarded as providing more favorable results. Flowers can effectively utilize gibberellin (GA) to substitute for fertilization, and fruit crops can employ it to trigger parthenocarpy (Shah *et al.,* 2023). Promalin, a synthetic derivative of gibberellins (GA_4 and GA_7), has been discovered to augment various growth and developmental processes, particularly in temperate fruit crops. Gibberellins assist in cell elongation and the growth of plant organs (Westfall *et al*., 2013).

Apple fruits that are encouraged to develop without seeds through gibberellin induction typically yield significantly more elongated fruit compared to regular seeded fruits. The use of GA_3 has also been noted to enhance the depth of the stem cavity in 'McIntosh' apples. The application of gibberellins leads to the development of parthenocarpic peach fruits that closely resemble those produced through pollination (Ghosh and Halder, 2018).

5.4 Gibberellic acid influence on sexual specification.

Gibberellin, a prominent phytohormone, not only supports typical growth and development but also influences the expression of sex in numerous plant species (Khryanin, 2002). Severe deficiency in gibberellin results in female sterility (Nester and Zeevaart, 1988; Goto and Pharis, 1999). In mutants with severe gibberellin deficiency, no functional pollen forms, and the sepals, petals, and pistils are stunted in growth, occasionally causing premature termination of the flower (Nester and Zeevaart, 1988; Goto and Pharis, 1999; Koornneef and Veen, 1980). The normal development of flowers can be restored by applying either bioactive gibberellins (GAs) or the gibberellin precursor GA_9 (Goto and Pharis, 1999).

Gibberellic acid (GA) plays a crucial role in both pollen germination and the growth of pollen tubes (Chhun *et al*., 2007; Singh *et al*. 2002) In mutants lacking gibberellic acid (GA), pollen grains fail to germinate unless supplemented with exogenous GA (Chhun *et al*., 2007). The development of stamens in the later stages, including filament elongation, anther dehiscence, and pollen maturation, is governed by gibberellic acid (GA) in coordination with jasmonic acid, while GA alone controls the early stages of anther development (Song *et al*., 2013).

6. Importance of gibberellic acid for yield.

6.1 Gibberellic acid for yield attributing characters.

The fruit yield typically relies on both the individual fruit's weight and the number of fruits per tree, collectively known as overall fruit development. This refers to the process wherein cells enlarge to produce larger fruit after the fruit has been successfully set on the tree. Gibberellins are most effective when administered during the stages of fruit development as they enhance both the size and yield of the fruit (Khinchi and Mondal, 2024). The application of GA_3 contributes to enhancements in the number of fruits per cluster, fruit set, and the number of marketable fruits per plant, as well as prolonging the time to maturity and extending the harvest period (Gelmesa*et al*., 2012).The addition of 75 ppm GA_3 affected the floral development per plant, total fruit production per plant, fruit set, and overall yield of fruit in *Fragaria ananassa*L. (Sharma and Singh, 2009). The foliar treatment of 50 mg/L GA_3 improved the number of buds, fruit set, average fruit weight, and yield in *Syzygiumsamarangense* L. (Moneruzzaman*et al*., 2011).

Nawaz *et al*., (2011) discovered that the highest fruit weight per plant (96.14 kg) was recorded with a 5 mg/l concentration of GA_3. Huang and Huang, (2005) noted that applying GA_3 at a concentration of 50 mg/l on citrus resulted in favorable outcomes, including the protection of fruitlets and enhanced yield in the 'Nanfengmiju' mandarin variety. Likewise, Saleem *et al*., (2008) noted that treating 15-year-old 'Blood Red' sweet orange plants with 45 mg/l of GA_3 at the full bloom stage resulted in a higher yield (71 kg/tree) compared to the control group (48 kg/tree). Fruit diameter holds significant commercial value in citrus fruit marketing and trade. Nawaz *et al*., (2008) discovered that the largest fruit size, measuring 71.20 mm, was achieved with a 10-ppm concentration of GA_3. Nawaz *et al*., (2011) studied that exogenous application of GA_3 resulted in a greater increase in fruit size. The fruit with the largest diameter (73.63 mm) was observed with a concentration of 10 mg/l GA_3.

7.Importance of gibberellic acid for post-harvest management.

7.1 Gibberellic acid for quality enhancement

Fruits play an important role in human nutrition and are highly recommended for maintaining a healthy diet. They are a rich provision of energy, minerals, vitamins, antioxidants, dietary fibers, and various phytochemicals. Whereas, Improper management after harvesting, such as inadequate storage and transportation facilities, due to unfavorable weather conditions, has led to substantial economic losses on a global scale (Yahia and Carrillo-Lopez, 2018). To overcome this issue, it is preferable to sustain the quality and quantity of consumable goods using a range of sustainable and environmentally friendly post-harvest preservation methods.

The exogenous application of GA_3 is an effective method that extends the shelf life of fruits (Kuchi *et al*., 2017). Gibberellic acids (GAs) have shown efficacy in enhancing the quality of fruit during storage, notably by substantially elevating flesh firmness, decreasing respiration rates, suppressing the production of natural ethylene, and effectively impeding fruit softening and ripening processes (Zhang *et al*., 2023). ‘Sweetheart’ cherries Cherries of the 'Sweetheart' variety treated with GA_3 at concentrations of 10 or 30 ppm exhibited notably higher firmness and revealed comparatively less stem browning (SB) at the end of cold storage compared to untreated fruit (Horvitz *et al*., 2002). When 'Bing' cherries were treated with a combination of GA_3 and Prohexadione-Ca (P-Ca), they displayed a notably increased proportion of green and turgid pedicels in comparison to those treated solely with P-Ca (Zhang and Whiting, 2011). It can also enhance both the inherent and external aspects of fruit preservation by refining fruit shape, controlling colour, postponing the decline in soluble solids, fostering sugar accumulation, and delaying the loss of vitamins.

GAs also contribute to postharvest resilience against both biotic and abiotic stresses. GA treatment efficiently diminishes the cold damage index, decreases the generation and build-up of superoxide anion (O2−), enhances the antioxidant capacity of fruits, and preserves the integrity of cell membranes during storage at low temperatures. Additionally, GAs demonstrate effective control over certain postharvest fruit diseases. In summary, GAs hold significant importance in the physiological regulation of postharvest fruits and offer promising prospects for their application in this context (Zhang *et al*., 2023).

7.2 Gibberellic acid for shelf-life enhancement.

Preserving natural products for extended periods without deterioration is a widespread necessity. While every fruit or vegetable has its lifespan, there's often a desire to extend it beyond expectations. Various preservatives are employed for this purpose, but some are avoided due to lingering side effects. Instead, coatings that can delay degradation and prolong shelf life are favored (Panigrahi*et al*., 2017). Yadav *et al*., (2022) investigated the use of various concentrations of $GA_3$for enhancing the fruits' ability to maintain freshness for extended periods, ranging from 4.25 to 7.17 days, by delaying their ripening. This approach has the potential to prolong the shelf life of mangoes. In contrast, mangoes treated with 400 ppm gibberellic acid demonstrated superior performance in preventing postharvest quality deterioration and extending the shelf life of mangoes.

Conclusion

Gibberellic acid (GA) exhibits remarkable versatility as a regulator of plant growth, development, and stress responses in fruit crops. Its multifaceted functions, including promoting vegetative growth, optimizing flowering and fruit set, and enhancing stress tolerance,ultimately contributing to enhanced yield potential in fruit crops underscore its significance in horticultural practices. Furthermore, GA exhibits remarkable efficacy in mitigating the detrimental effects of abiotic stresses on fruit crops. By modulating plant responses to environmental cues, GA helps plants withstand adverse conditions such as drought, salinity, and extreme temperatures. Its involvement in stress tolerance mechanisms equips fruit crops with resilience, ensuring sustained productivity even under challenging circumstances. GA-mediated interventions hold great potential for meeting consumer demands for premium-quality produce. Utilizing GA strategically holds great promise for maximizing fruit yield, quality, and resilience in the face of environmental challenges, thereby offering valuable opportunities for sustainable fruit crop management. Gibberellic acid emerges as a valuable asset in the pursuit of sustainable and high-yielding fruit crop production growers can unlock the potential for ensuring both economic prosperity and nutritional security in a dynamic horticultural landscape.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

References

Abbas, H. M. K.; Askri, S. M. H.; Ali, S.; Fatima, A.; Qamar, M. T. U.; Xue, S. D.; Muhammed, Z.; Akram, w. and Zhong, Y. J. (2022). Mechanism associated with brassinosteroids crosstalk with gibberellic acid in plants. In *Brassinosteroids Signalling: Intervention with Phytohormones and Their Relationship in Plant Adaptation to Abiotic Stresses.,* Singapore: Springer Singapore. 101-115. https://doi.org/10.1007/978-981-16-5743-6_6.

Achard, P. and Genschik, P. (2009). Releasing the brakes of plant growth: how GAs shutdown DELLA proteins. *Journal of experimental botany*., *60*(4): 1085-1092. https://doi.org/10.1093/jxb/ern301.

Achard, P.; Gusti, A.; Cheminant, S.; Alioua, M.; Dhondt, S.; Coppens, F.; Beemstar, G.T.S. and Genschik, P. (2009). Gibberellin signaling controls cell proliferation rate in Arabidopsis. *Current biology*., *19*(14): 1188-1193. https://doi.org/10.1016/j.cub.2009.05.059.

Alhadi, A. F.; Yasseen, B. T. and Jabr, M. (1999). Water stress and gibberellic acid effects on growth of fenugreek plants. *Irrigation Science*., 18: 185-190. https://doi.org/10.1007/s002710050061.

Al-Shaheen, M.R. and Soh, A. (2016). Effect of proline and Gibberellic Acid on the qualities and qualitative of Corn (*Zea maize* L.) under the influence of different levels of the water stress. *Int J Sci Res Pub*., 6(5):752–756.

Anwar, A.; Bai, L.; Miao, L.; Liu, Y.; Li, S.; Yu, X. and Li, Y. (2018). 24-Epibrassinolide ameliorates endogenous hormone levels to enhance low-temperature stress tolerance in cucumber seedlings. *International Journal of Molecular Sciences*., *19*(9): 2497. https://doi.org/10.3390/ijms19092497.

Aslam, M.M.; Waseem, M.; Jakada, B. H.; Okal, E. J.; Lei, Z.; Saqib, H.; Yuan, W.; Xu, W.and Zhang, Q. (2022). Mechanisms of abscisic acid-mediated drought stress responses in plants. *International journal of molecular sciences*., *23*(3); 1084. https://doi.org/10.3390/ijms23031084.

Bejaoui, M. (1985). Intéractions entre NaCl et quelques Phytohormones sur la croissance du Soja: interactions between NaCl and some phytohormones on soybean growth. Journal of plant physiology., 120(2): 95-110. https://doi.org/10.1016/S0176-1617(85)80014-6.

Bewley, J. D. (1997). Seed germination and dormancy. *The plant cell*., *9*(7): 1055. https://doi.org/10.1105/tpc.9.7.1055.

Chhun, T.; Aya, K.; Asano, K.; Yamamoto, E.; Morinaka, Y.; Watanabe, M.; Kitano,H.; Ashikari, M.; Matsuoka,M. and Tanaka, U.M. (2007). Gibberellin regulates pollen viability and pollen tube growth in rice. *Plant Cell*.,19:3876–88. https://doi.org/10.1105/tpc.107.054759.

Colebrook, E. H.; Thomas, S. G.; Phillips, A. L.; and Hedden, P; (2014). The role of gibberellin signalling in plant responses to abiotic stress. *Journal of experimental biology*., 217(1): 67-75. https://doi.org/10.1242/jeb.089938.

Criado, M. V.; Veliz, C. G.; Roberts, I. N. and Caputo, C. (2017). Phloem transport of amino acids is differentially altered by phosphorus deficiency according to the nitrogen availability in young barley plants. *Plant Growth Regulation*.,*82*: 151-160. https://doi.org/10.1007/s10725-017-0247-6.

Chitra, M., Roopa, S., Sivakumar, P., Prabha, T., Karunakaran, V., Sujatha, P. & Selvaraj, V. (2022). A recent report on the effect of moringa leaf (*Moringa oleifera* Lam.) as a biostimulant in the growth and physiochemical traits of agricultural crops. *Annals of phytomedicine*, 11(2), 224-230. nals of Phytomedicine 11(2): 224-230, 2022 Annals of Phytomedicine,http://dx.doi.org/10.54085/ap.2022.11.2.24.

Dagar, A.; Weksler, A.; Friedman, H. and Lurie, S. (2012). Gibberellic acid (GA3) application at the end of pit ripening: Effect on ripening and storage of two harvests of ‘September Snow’peach. *Scientia Horticulturae*., *140*: 125-130. https://doi.org/10.1016/j.scienta.2012.03.013.

Davidson, S. E.; Reid, J. B. and Helliwell, C. A. (2006). Cytochromes P450 in gibberellin biosynthesis. *Phytochemistry Reviews*., *5*: 405-419. https://doi.org/10.1007/s11101-006-9005-5.

Davière, J.M. and Achard, P. (2013) Gibberellin signaling in plants. *Development*.,140 (6):1147–1151. https://doi.org/10.1242/dev.087650.

Davies, F. S. and Zalman, G. (2006). Gibberellic Acid, Fruit Freezing, and Post-freeze Quality of Hamlin'Oranges. *HortTechnology*., *16*(2):301-305.

Ding, Y.; Sheng, J.; Li, S.; Nie, Y.; Zhao, J.; Zhu, Z.; Wang, Z. and Tang, X. (2015). The role of gibberellins in the mitigation of chilling injury in cherry tomato (*Solanum lycopersicum* L.) fruit. *Postharvest Biology and Technology*.,*101*: 88-95. https://doi.org/10.1016/j.postharvbio.2014.12.001.

Elahi, N. N.; Raza, S.; Rizwan, M. S.; Albalawi, B. F. A.; Ishaq, M. Z.; Ahmed, H. M., Mehmood, S.; Imtiaz, M.; Farooq, U.; Rashid, M. and Ditta, A. (2022). Foliar application of gibberellin alleviates adverse impacts of drought stress and improves growth, physiological and biochemical attributes of canola (*Brassica napus* L.). *Sustainability*, *15*(1), 78. **https://doi.org/10.3390/su15010078.**

Emamverdian, A.; Ding, Y. and Mokhberdoran, F. (2020). The role of salicylic acid and gibberellin signaling in plant responses to abiotic stress with an emphasis on heavy metals. *Plant signaling and behaviour*.,*15*(7): 1777372. https://doi.org/10.1080/15592324.2020.1777372.

Finkelstein, R.; Reeves, W.; Ariizumi, T. and Steber, C. (2008). Molecular aspects of seed dormancy. *Annu. Rev. Plant Biol.*, *59*: 387-415. **https://doi.org/10.1146/annurev.arplant.59.032607.092740.**

Gelmesa, D.; Bekele, A. and Desalegn, L. (2012). Regulation of tomato (*Lycopersicon esculentum Mill*.) fruit setting and earliness by gibberellic acid and 2, 4-dichlorophenoxy acetic acid application. *African journal of biotechnology*., 11(51):11200-11206. https://doi.org/10.5897/AJB11.2928.

Ghosh, S. and Halder, S. (2018). Effect of different kinds of gibberellin on temperate fruit crops: A review. *The Pharma Innovation Journal*., *7*(3): 315-319.

Gill, S. S.; Anjum, N. A.; Hasanuzzaman, M.; Gill, R.; Trivedi, D. K.; Ahmad, I.; Pereria E. and Tuteja, N. (2013). Glutathione and glutathione reductase: a boon in disguise for plant abiotic stress defense operations. *Plant physiology and biochemistry*., 70: 204-212. https://doi.org/10.1016/j.plaphy.2013.05.032.

Goto, N. and Pharis, R. P. (1999). Role of gibberellins in the development of floral organs of the gibberellin-deficient mutant, ga1-1, of Arabidopsis thaliana. *Canadian Journal of Botany*., *77*(7): 944-954. https://doi.org/10.1139/b99-090.

Griffiths, J.; Murase, K.; Rieu, I.; Zentella, R.; Zhang, Z. L.; Powers, S. J.; Gong, F.; Phillips A.L.; Hedden, P.; Sun, T.P. and Thomas, S. G. (2006). Genetic characterization and functional analysis of the GID1 gibberellin receptors in Arabidopsis. *The Plant Cell*., *18*(12): 3399-3414. https://doi.org/10.1105/tpc.106.047415.

Gupta, R. and Chakrabarty, S. K. (2013). Gibberellic acid in plant: still a mystery unresolved. *Plant signaling& behaviour*., *8*(9): e25504. https://doi.org/10.4161/psb.25504.

Hakeem, K. R.; Khan, F.; Chandna, R.; Siddiqui, T. O. and Iqbal, M. (2012). Genotypic variability among soybean genotypes under NaCl stress and proteome analysis of salt-tolerant genotype. *Applied biochemistry and biotechnology*., *168*: 2309-2329. https://doi.org/10.1007/s12010-012-9939-6.

Hamayun, M.; Khan, S. A.; Khan, A. L.; Shin, J. H.; Ahmad, B.; Shin, D. H. and Lee, I. J. (2010). Exogenous gibberellic acid reprograms soybean to higher growth and salt stress tolerance. *Journal of agricultural and food chemistry*., *58*(12): 7226-7232. https://doi.org/10.1021/jf101221t.

Hedden, P. (2020). The current status of research on gibberellin biosynthesis. *Plant and Cell Physiology*., *61*(11):1832-1849. https://doi.org/10.1093/pcp/pcaa092.

Hedden, P. (2020). The current status of research on gibberellin biosynthesis. *Plant and Cell Physiology*., *61*(11):1832-1849. https://doi.org/10.1093/pcp/pcaa092.

Hedden, P. and Thomas, S.G. (2012) Gibberellin biosynthesis and its regulation. *Biochem J*., 444. https://doi.org/10.1042/BJ20120245.

Hedden, P.; Phillips, A. L.; Rojas, M. C.; Carrera, E. and Tudzynski, B. (2001). Gibberellin biosynthesis in plants and fungi: a case of convergent evolution?. *Journal of Plant Growth Regulation*., *20*(4). https://doi.org/10.1002/j.1537-2197.1988.tb12160.x.

Hedden, P.; Phillips, A.L.; Rojas, M.C.; Carrera, E. and Tudzynski, B. (2002) Gibberellin biosynthesis in plants and fungi: a case of convergent evolution. *J Plant Growth Regul*., 20:319–331. https://doi.org/10.1007/s003440010037.

Horvitz, S.; Godoy, C.; López Camelo, A. F. and Yommi, A. (2002). Application of gibberellic acid to 'Sweetheart' sweet cherries: effects on fruit quality at harvest and during cold storage. In XXVI International Horticultural Congress: *Issues and Advances in Postharvest Horticulture 628*: 311-316. https://doi.org/10.17660/ActaHortic.2003.628.37.

Hu, Z.; Weijian, L.; Yali, F. and Huiquan, L. (2018). Gibberellic acid enhances postharvest toon sprout tolerance to chilling stress by increasing the antioxidant capacity during the short-term cold storage. *Scientia horticulturae*., *237*; 184-191. https://doi.org/10.1016/j.scienta.2018.04.018.

Huang JunHe, H. J. and Huang LiXin, H. L. (2005). The application of GA_3 in citrus orchards.

Hussain, S. F., Reddy, P. S. S., Reddy, M. L. N., Murthy, B. N. S., Upreti, K. K., Laxman, R. H. and Srinivasulu, B. (2021). Studies on flower induction and improvement of fruit yield and its attributes in pomegranate (Punica granatum L.) CV. Bhagwa. *Annals of Phytomedicine*., *10*(1), 277-288. http://dx.doi.org/10.21276/ap.2021.10.1.30.

Illouz-Eliaz, N.; Nissan, I.; Nir, I.; Ramon, U.; Shohat, H. and Weiss, D. (2020). Mutations in the tomato gibberellin receptors suppress xylem proliferation and reduce water loss under water-deficit conditions. *Journal of Experimental Botany*., *71*(12): 3603-3612. https://doi.org/10.1093/jxb/eraa137.

Isayenkov, S.V.; Maathuis, F.J.; (2019). Plant salinity stress: many unanswered questions remain. *Front Plant Sci*.,10:80. https://doi.org/10.3389/fpls.2019.00080.

Islam, S.; Zaid, A. and Mohammad, F. (2021). Role of triacontanol in counteracting the ill effects of salinity in plants: a review. *Journal of Plant Growth Regulation*., 40(1): 1-10. https://doi.org/10.1007/s00344-020-10064-w.

Kasahara, H.; Hanada, A.; Kuzuyama, T.; Takagi, M.; Kamiya, Y. and Yamaguchi, S. (2002). Contribution of the mevalonate and methylerythritol phosphate pathways to the biosynthesis of gibberellins in Arabidopsis. *Journal of Biological Chemistry*., *277*(47) :45188-45194. https://doi.org/10.1074/jbc.M208659200.

Kaur, G. and Asthir, B. (2017). Molecular responses to drought stress in plants. *Biologia plantarum*., *61:* 201-209. https://doi.org/10.1007/s10535-016-0700-9.

Kaur, S.; Gupta, A. K. and Kaur, N. (1998). Gibberellin A3 reverses the effect of salt stress in chickpea (*Cicer arietinum* L.) seedlings by enhancing amylase activity and mobilization of starch in cotyledons. *Plant Growth Regulation*., 26: 85-90. https://doi.org/10.1023/A:1006008711079.

Khan, SU.; Gurmani, AR.; Jalal-Ud-Din, JD.; Abbasi, KS.; Liaquat, M. and Ahmad, Z. (2016) Exogenously applied gibberellic acid, indole acetic acid and kinetin as potential regulators of source-sink relationship, physiological and yield attributes in rice (*Oryza sativa*) genotypes under water deficit conditions. *Int J Agric Biol*., 18:139–145.

Khinchi, A. and Mondal, K. (2024). Role of gibberellic acid in fruit set, yield and quality improvement of custard apple (*Annona squamosa* L.). *Agri roots e-magazine*., 2(3).

Khryanin, V. N. (2002). Role of phytohormones in sex differentiation in plants. *Russian Journal of Plant Physiology*., *49*: 545-551.

Kim, S. G. and Park, C. M. (2008). Gibberellic acid-mediated salt signaling in seed germination. *Plant Signaling and Behavior*, *3*(10): 877-879. https://doi.org/10.4161/psb.3.10.6247.

King, W.R; Moritz, T., Evans, L. T.; Martin, J.; Andersen, C. H.; Blundell, C.; Kardailsky, I. and Chandler, P. M. (2006). Regulation of flowering in the long-day grass *Lolium temulentum* by gibberellins and the FLOWERING LOCUS T gene. *Plant Physiology*., *141*(2): 498-507. https://doi.org/10.1104/pp.106.076760.

Koornneef, M. and Van der Veen, J. H. (1980). Induction and analysis of gibberellin sensitive mutants in Arabidopsis thaliana (L.) heynh. *Theoretical and Applied genetics*., *58*: 257-263. https://doi.org/10.1007/BF00265176

Kucera, B.; Cohn, M. A. and Leubner-Metzger, G. (2005). Plant hormone interactions during seed dormancy release and germination. *Seed science research*., *15*(4): 281-307.

Kuchi, V. S.; Kabir, J. and Siddiqui, M. W. (2017). Gibberellins: the roles in pre-and postharvest quality of horticultural produce. *Postharvest Management of Horticultural Crops.*, 181-230.

Leubner-Metzger, G. (2006). Seed dormancy and the control of germination. *New phytol*., *171*:501-523.

Li, C.; Zheng, L.; Wang, X.; Hu, Z.; Zheng, Y.; Chen, Q.; Hao, X.; Xiao, X.; Wang, X.; Wang, G. and Zhang, Y. (2019). Comprehensive expression analysis of Arabidopsis GA_2-oxidase genes and their functional insights., *Plant Science*., *285*: 1-13. https://doi.org/10.1016/j.plantsci.2019.04.023.

Li, Z.; Lu, G. Y.; Zhang, X. K.; Zou, C. S.; Cheng, Y. and Zheng, P. Y. (2010). Improving drought tolerance of germinating seeds by exogenous application of gibberellic acid (GA_3) in rapeseed (*Brassica napus* L.). *Seed Science and Technology*., *38*(2): 432-440. https://doi.org/10.15258/sst.2010.38.2.16.

Looney, N. E. and Lidster, P. D. (1980). Some growth regulator effects on fruit quality, mesocarp composition, and susceptibility to postharvest surface marking of sweet cherries1. *Journal of the American Society for Horticultural Science*.,*105*(1): 130-134.

MacNeill, G. J.; Mehrpouyan, S.; Minow, M. A.; Patterson, J. A.; Tetlow, I. J. and Emes, M. J. (2017). Starch as a source, starch as a sink: the bifunctional role of starch in carbon allocation. *Journal of experimental botany*., *68*(16): 4433-4453. https://doi.org/10.1093/jxb/erx291.

Manzoor, M. A.; Xu, Y.; Lv, Z.; Xu, J.; Wang, Y.; Sun, W.; Liu, X.; Wang, L.; Wang, J.; Liu, R.; Whiting, M.; Jiu, S. and Zhang, C. (2023). Fruit crop abiotic stress management: a comprehensive review of plant hormones mediated responses. *Fruit Research*.,*3*(1) https://doi.org/10.48130/FruRes-2023-0030.

Mathur, S.; Agrawal, D.andJajoo, A. (2014). Photosynthesis: response to high temperature stress. *J PhotochemPhotobiol Biol*., 137:116–126. https://doi.org/10.1016/j.jphotobiol.2014.01.010.

Moneruzzaman, K. M.; Hossain, A. B. M. S.; Normaniza, O. and Boyce, A. N. (2011). Growth, yield and quality responses to gibberellic acid (GA_3) of Wax apple *Syzygiumsamarangense* var. Jambu air madu fruits grown under field conditions. *African Journal of Biotechnology*., *10*(56): 11911-11918. https://doi.org/10.5897/AJB10.1692.

Munns, R. and Tester, M. (2008). Mechanisms of salinity tolerance. Annu. Rev. *Plant Biol.*, 59: 651-681. **https://doi.org/10.1146/annurev.arplant.59.032607.092911.**

Nawaz, M. A.; Afzal, M.; Ahmed, W.; Ashraf, M.; Silva, J. A. T.; Akhtar, N.; Shahzad, S.M.; Ullah, H. and Hussain, Z. (2011). Exogenous application of 2, 4-D, GA_3 and NAA at flowering improves yield and quality of Kinnow mandarin (*Citrus reticulata Blanco*). *Asian and Australasian Journal of Plant Science and Biotechnology*., *5*(1) :17-21.

Nawaz, M. A.; Ahmad, W.; Ahmad, S. and Khan, M. M. (2008). Role of growth regulators on preharvest fruit drop, yield and quality in Kinnow mandarin. *Pak. J. Bot*., *40*(5): 1971-1981.

Nester, J. E. and Zeevaart, J. A. (1988). Flower development in normal tomato and a gibberellin- deficient (ga- 2) mutant. *American Journal of Botany*., *75*(1): 45-55.

Nir, I. D. O.; Moshelion, M. and Weiss, D. (2014). The A rabidopsisGibberellin Methyl Transferase 1 suppresses gibberellin activity, reduces whole- plant transpiration and promotes drought tolerance in transgenic tomato. *Plant, cell and environment*., *37*(1): 113-123. **https://doi.org/10.1111/pce.12135.**

Negi. and Sharma. (2022). Diversity and bioprospecting potential of PGPR from critically endangered medicinal plant, *Trillium govanianum* (Wall. ex D. on) in North-West Himalayas. Annals of phytomedicine. :https://doi.org/10.54085/ap.2022.11.1.64.

Ogawa, M.; Hanada, A.; Yamauchi, Y.; Kuwahara, A.; Kamiya, Y. and Yamaguchi, S. (2003). Gibberellin biosynthesis and response during Arabidopsis seed germination. *The Plant Cell*., *15*(7): 1591-1604. https://doi.org/10.1105/tpc.011650.

Othman, Y. A. and Leskovar, D. I. (2022). Foliar application of gibberellic acid improves yield and head phenolic compounds in globe artichoke. *Scientia Horticulturae*, *301*: 111115. https://doi.org/10.1016/j.scienta.2022.111115.

Panigrahi, J. P.; Gheewala, B. G.; Patel, M.; Patel, N.; and Gantait, S; (2017). Gibberellic acid coating: a novel approach to expand the shelf-life in green chilli (*Capsicum annuum* L.). *Scientia Horticulturae*, 225:581-588. https://doi.org/10.1016/j.scienta.2017.07.059

Parihar, P.; Singh, S.; Singh, R.; Singh, V. P. and Prasad, S. M. (2015). Effect of salinity stress on plants and its tolerance strategies: a review. *Environmental science and pollution research*., *22*: 4056-4075. https://doi.org/10.1007/s11356-014-3739-1.

Piskurewicz, U.; Jikumaru, Y.; Kinoshita, N.; Nambara, E.; Kamiya, Y. and Lopez-Molina, L. (2008). The gibberellic acid signaling repressor RGL2 inhibits Arabidopsis seed germination by stimulating abscisic acid synthesis and ABI5 activity. *The Plant Cell*., *20*(10): 2729-2745. https://doi.org/10.1105/tpc.108.061515.

Rademacher, W. (2015). Plant growth regulators: backgrounds and uses in plant production. *Journal of plant growth regulation*., *34*: 845-872. https://doi.org/10.1007/s00344-015-9541-6.

Ramesh, B. and Kumar, B. (2006). Response of induced dwarf mutants of barley to exogenous application of gibberellic acid. *Barley genetics newsletter*., *36*: 3-5.

Ravindran, P. and Kumar, P. P. (2019). Regulation of seed germination: The involvement of multiple forces exerted via gibberellic acid signaling. *Molecular plant*., 12(1): 24-26. https://doi.org/10.1016/j.molp.2018.12.013.

Saade, S.; Maurer, A.; Shahid, M.; Oakey, H.; Schmöckel, S. M.; Negrão, S.; Pillen, K. and Tester, M. (2016). Yield-related salinity tolerance traits identified in a nested association mapping (NAM) population of wild barley. *Scientific reports*., 6(1): 32586. https://doi.org/10.1038/srep32586.

Sabagh, E.A.; Islam, S.M.; Hossain, A.; Iqbal, M.A.; Mubeen, M.; Waleed, M.; Reginato, M.; Battaglia, M.; Ahmed, S.; Rehman,A.; Arif, Muhammed.; Athar,H.U.R.; Ratnasekera, D.; Danish, S.; Raza, M.A.; Rajendran, K.; Mushtaq, M.; Skalicky, M.; Bretic, M.; Walid, S.; Fahad, S.; Pandey,S.; Kamran,M.; Datta, R. and Abdelhamid,T.M. (2022). Phytohormone as a regulator during abiotic stress tolerance in plants. Front.Agron., 4.

Salazar-Cerezo, S.; Martínez-Montiel, N.; García-Sánchez, J.; Pérez-y-Terrón, R. and Martínez-Contreras, R. D. (2018). Gibberellin biosynthesis and metabolism: A convergent route for plants, fungi and bacteria. *Microbiological research*., *208*: 85-98. https://doi.org/10.1016/j.micres.2018.01.010.

Saleem, B. A.; Malik, A. U.; Pervez, M. A. and Khan, A. S. (2008). Growth regulators application affects vegetative and reproductive behaviour of 'Blood Red'sweet orange. *Pak. J. Bot*., *40*(5): 2115-2125.

Saleem, M.H.; Fahad, S.; Adnan, M.; Ali, M.; Rana, MS.; Kamran. and Hussain, R.M. (2020). Foliar application of gibberellic acid endorsed phytoextraction of copper and alleviates oxidative stress in jute (*Corchorus capsularis* L.) plants grown in highly copper-contaminated soil of China. *Environ Sci Pollut Res*., 27:37121–37133. https://doi.org/10.1007/s11356-020-09764-3.

Schwechheimer, C. (2008). Understanding gibberellic acid signalling—are we there yet? *Current opinion in plant biology*., *11*(1): 9-15. https://doi.org/10.1016/j.pbi.2007.10.011.

Seleiman, M. F.; Al-Suhaibani, N.; Ali, N.; Akmal, M.; Alotaibi, M.; Refay, Y.; Dindaroglu, T.; Wajid, H.H.A. and. Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*., *10*(2): 259. https://doi.org/10.3390/plants10020259.

Seleiman, M.F.; Al-Suhaibani, N.; Ali, N.; Akmal, M.; Alotaibi, M.; Refay, Y. and Battaglia, M.L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants.*, 10(2):259. https://doi.org/10.3390/plants10020259.

Shah, S. H.; Islam, S. and Mohammad, F. (2022a). Sulphur as a dynamic mineral element for plants: A review. *Journal of Soil Science and Plant Nutrition*., *22*(2): 2118-2143. https://doi.org/10.1007/s42729-022-00798-9.

Shah, S. H.; Islam, S.; Alamri, S.; Parrey, Z. A.; Mohammad, F. and Kalaji, H. M. (2023). Plant growth regulators mediated changes in the growth, photosynthesis, nutrient acquisition, and productivity of mustard. *Agriculture*., *13*(3): 570. https://doi.org/10.3390/agriculture13030570.

Shah, S. H.; Islam, S.; Parrey, Z. A. and Mohammad, F. (2021). Role of exogenously applied plant growth regulators in growth and development of edible oilseed crops under variable environmental conditions: A review. *Journal of Soil Science and Plant Nutrition*., 21(4): 3284-3308.https://doi.org/10.1007/s42729-021-00606-w.

Shah, S. H.; Parrey, Z. A.; Islam, S.; Tyagi, A.; Ahmad, A. and Mohammad, F. (2022b). Exogenously Applied Sulphur Improves Growth, Photosynthetic Efficiency, Enzymatic Activities, Mineral Nutrient Contents, Yield and Quality of *Brassica juncea* L. *Sustainability*., *14*(21): 14441. **https://doi.org/10.3390/su142114441.**

Shaheen, M. R.A. and Soh, A. (2016). Effect of proline and Gibberellic Acid on the qualities and qualitative of Corn (*Zea maize* L.) under the influence of different levels of the water stress. *Int. J. Sci. Res. Publ*., *6*: 752-756.

Sharma, R. R. and Singh, R. (2009). Gibberellic acid influences the production of malformed and button berries, and fruit yield and quality in strawberry (*Fragaria*× *ananassa*Duch.). *Scientia Horticulturae*., *119*(4): 430-433. https://doi.org/10.1016/j.scienta.2008.11.002.

Sharma, P.; Roy, M. and Roy, B. (2022). A review on influence of floral biology, pollination efficiency and conservation strategies of endangered medicinal plant, *Rauvolfiaserpentina* (L.) Benth. ex Kurz. *Annals of Phytomedicine*, 11(1), 86-98. http://dx.doi.org/10.54085/ap.2022.11.1.9.

Singh, D.P.; Jermakow, A.M. and Swain, S.M. (2002). Gibberellins are required for seed development and pollen tube growth in Arabidopsis. *Plant Cell*., 14: 3133–3147. https://doi.org/10.1105/tpc.003046.

Song, S.; Qi, T.; Huang, H. and Xie, D. (2013). Regulation of stamen development by coordinated actions of jasmonate, auxin, and gibberellin in Arabidopsis. *Molecular Plant*.,*6*(4): 1065-1073. https://doi.org/10.1093/mp/sst054.

Sun, T.P. and Gubler, F. (2004) Molecular mechanism of gibberellin signaling in plants. *Annu Rev Plant Biol*., 55:197–223. https://doi.org/10.1146/annurev.arplant.55.031903.141753.

Szymańska, R.; Ślesak, I.; Orzechowska, A. and Kruk, J. (2017). Physiological and biochemical responses to high light and temperature stress in plants. *Environ Exp Bot*., 139:165–177. https://doi.org/10.1016/j.envexpbot.2017.05.002.

Temgire, S., Mirza, A. A., Wani, A. W., Ravi, K., Tanpure, P. and Kadlag, S. (2023). Unveiling the potential: Colour enhancement and pharmaceutical properties of Crimson Seedless grapes. *Annals of Phytomedicine*, *12*(1), 105-114. http://dx.doi.org/10.54085/ap.2023.12.1.86.

Ueguchi-Tanaka, M.; Nakajima, M.; Katoh, E.; Ohmiya, H.; Asano, K.; Saji, S.; Hongyu, X.; Ashikari, M.; Kitano, H.; Yamaguchi, I. and Matsuoka, M. (2007). Molecular interactions of a soluble gibberellin receptor, GID1, with a rice DELLA protein, SLR1, and gibberellin. *The Plant Cell*., *19*(7): 2140-2155. https://doi.org/10.1105/tpc.106.043729.

Van Schie, C. C.; Ament, K.; Schmidt, A.; Lange, T.; Haring, M. A. and Schuurink, R. C. (2007). Geranyl diphosphate synthase is required for biosynthesis of gibberellins. *The Plant Journal*., *52*(4): 752-762. https://doi.org/10.1111/j.1365-313X.2007.03273.x.

Westfall, C.S.; Muehler, A.M. and Jez, J.M. (2013). Enzyme action in the regulation of plant hormone responses. *Journal of Biological Chemistry*., 288(27):19304-19311. https://doi.org/10.1074/jbc.R113.475160.

Witcombe, J. R.; Hollington, P. A.; Howarth, C. J.; Reader, S. and Steele, K. A. (2008). Breeding for abiotic stresses for sustainable agriculture. *Philosophical Transactions of the Royal Society B: Biological Sciences*., *363*(1492): 703-716. https://doi.org/10.1098/rstb.2007.2179.

Yadav, S.; Yadav, S. P. S.; Adhikari, N.; Sah, R. K. and Gupta, S. (2022). Effects of Gibberellic acid (GA3) on shelf life and physiochemical properties of mango (*Mangifera indica* L. var Bombay green). *Archives of Agriculture and Environmental Science*., *7*(4): 541-548. https://doi.org/10.26832/24566632.2022.0704010.

Yahia, E. M. and Carrillo-Lopez, A. (2018). *Postharvest physiology and biochemistry of fruits and vegetables*., Woodhead publishing.

Yoshida, H.; Hirano, K.; Sato, T.; Mitsuda, N.; Nomoto, M.; Maeo, K.; Koketsu, E.; Mitani, R.; Kawamura, M.; Ishiguro S.; Tada,Y.; Ohme-Takagi, M.; Matsuoka,M.; and Ueguchi-Tanaka, M. (2014). DELLA protein functions as a transcriptional activator through the DNA binding of the indeterminate domain family proteins. *Proceedings of the National Academy of Sciences*., *111*(21), 7861-7866. https://doi.org/10.1073/pnas.1321669111.

Zhang, C., and Whiting, M. (2011). Pre-harvest foliar application of Prohexadione-Ca and gibberellins modify canopy source-sink relations and improve quality and shelf-life of ‘Bing’sweet cherry. *Plant Growth Regulation*., *65*:145-156. https://doi.org/10.1007/s10725-011-9584-z.

Zhang, J.; Cao, Y.; Tang, J.; He, X.; Li, M.; Li, C.; Ren, X. and Ding, Y. (2023). Physiology and application of gibberellins in postharvest horticultural crops. *Horticulturae*., 9(6): 625. https://doi.org/10.3390/horticulturae9060625.

Zhao, R.; Sheng, J.; Lv, S.; Zheng, Y.; Zhang, J.; Yu, M. and Shen, L. (2011). Nitric oxide participates in the regulation of LeCBF1 gene expression and improves cold tolerance in harvested tomato fruit. *Postharvest Biology and Technology*., *62*(2): 121-126. https://doi.org/10.1016/j.postharvbio.2011.05.013.

Zhu, J. K. (2016). Abiotic stress signalling and responses in plants. *Cell*., *167*(2): 313-324. https://doi.org/10.1016/j.cell.2016.08.029.