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γ- aminobutyric acid (GABA) Shunt Pathway in Regulation of Drought Tolerance in Plants

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Overview

GABA shunt pathway is the metabolic pathway of the γ- aminobutyric acid biosynthesis in plants. GABA synthesized in plants plays major role in the mitigation of drought stress. GABA tends to have protective effect against water deficit conditions through accelerating turgor potential and osmolytes. GABA may also reduce oxidative damage through antioxidant regulation. Therefore, GABA–induced stomatal conductance has gained attention in regulating drought-responsive elements by leading as a plant signaling molecule. We summarized GABA–induced signaling to increase the drought tolerance mechanism in the plants.

1. Introduction

Drought is one of the most important constraints of the plant growth and productivity across the world. The amplitude of drought stress has increased in recent years due to anthropogenic activities. Drought stress has been identified as one of the most damaging stressors among other abiotic stresses (Vanani, et al., 2020). However, identifying mechanisms to counteract drought stress is the strategies to maintain the growth and development of plants under harsh water deficit conditions. Recent investigations have shown that the GABA shunt pathway may prove to be an important mechanism to reduce the effect of drought stress by targeting oxidative damages, reactive oxygen species (ROS), turgor potential, and stomatal conductance (Noctor, et al., 2018). In this article, we summarize and critically assess the role GABA plays in plant growth and development involved in the regulation of physiological and biochemical processes in the plant under drought stressed condition. We also describe the recent success in the development of drought tolerance in crop plants

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employing GABA–induced signaling and their manipulation to accelerate drought tolerance in plants.

2. γ- aminobutyric acid (GABA)

γ- aminobutyric acid (GABA) is the non–protein part of amino acid discovered in potatoes and found in almost all prokaryotic and eukaryotic species (Steward, 1949). GABA plays an important role in amino acid biosynthesis and a majority of the nitrogen metabolism. In addition, it also acts as a signaling molecule in the growth and development of plants by interfering with physiological and biochemical processes in the plants (Li, et al., 2021). Rather than the growth and development of the plants, it is quickly accumulated in the abiotic stress-affected plant tissues to reduce the effect of abiotic factors like drought, high temperature, and salinity. Hence, exogenous applications of GABA have to increase the antioxidant activity as well as glyoxylate mechanism in response to methylglyoxal (MG) detoxification (Rashmi, et al., 2018).

3. GABA biosynthesis in plants

The GABA shunt pathway is the rout of GABA biosynthesis in plants. Apart from GABA biosynthesis, the GABA shunt pathway would like to optimize the GABA level in plants (Clark, et al., 2009). GABA biosynthesis through GABA shunt may catalysed by the cytosolic enzyme glutamate decarboxylase (GAD), succinic semi-aldehyde dehydrogenase (SSADH), and one more mitochondrial

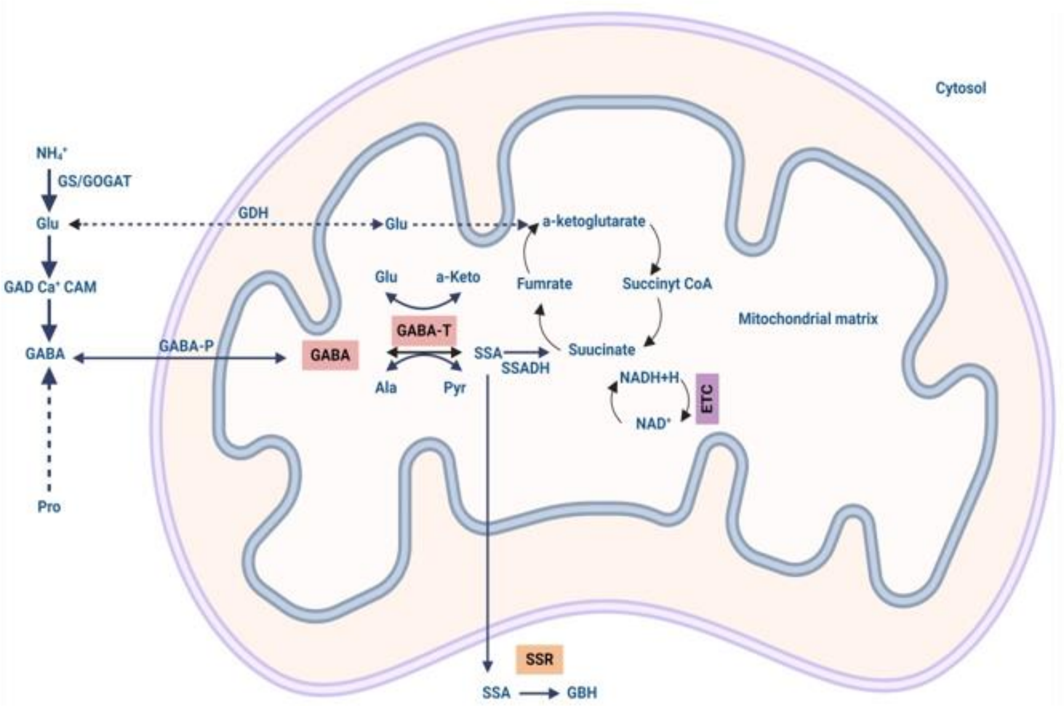

Figure: *Mechanism of GABA biosynthesis in plants* enzyme GABA transaminase (Akihiro, et al., 2008). During GABA biosynthesis, GAD catalyses α-decarboxylation of glutamate to GABA. In the next step of the GABA biosynthesis, GABA is transformed to succinic semi-aldehyde employing GABA transaminase (GABA-T) which alternately is transformed to succinate by SSADH. The next step is the production of the alanine and glycine through GABA-T as amino acceptor with the help of pyruvate and glyoxylate (Shelp, et al., 2012).

A critical study revealed that GABA-T prefers 2-oxyglutarate to pyruvate for GAD response in the plant system. However, succinate enters the TCA cycle involve in electron transportation as an electron donor or releases succinate from SSADH and enters the TCA cycle (Priya, et al., 2019). Later, SSA converted to γ-hydroxy-butyrate (GHB) with the help of the enzyme GHB dehydrogenase. The mechanism of GABA biosynthesis is well illustrated in the figure.

4. Role of GABA in drought tolerance resistance development in plants

Drought is one of the devastating abiotic stresses damaging cellular components of plants due to overproduction of reactive oxygen species (Jahan, et al., 2021). Some metabolites like GABA, *Ala*, and *Glu* are associated with GABA shunt in response to ROS generation under stressed conditions. Certain reactive oxygen species like hydrogen peroxide (H_2O_2) may activate signal transduction pathways in plant cells and a decrease in the NADPH in the nucleus (Waseem, et al., 2021). Hydrogen peroxide (H_2O_2) may provide strength for the development of safeguard processes against hydrogen peroxide toxicity. In addition, ROS promotes mitochondrial glutamate dehydrogenase enzyme activity providing *Glu* as precursor for Ornithine and GABA production (Hasan, et al., 2018). Thus, GABA provides a protective role against oxidative stress through osmotic adjustment for the development of drought tolerance in plants.

In several studies, it has been found that sufficient biosynthesis of GABA under drought stress efficiently reduces leaf damage by increasing the relative water content and decreasing lipid peroxidation. Moreover, over accumulation of amino acids and osmolytes due to excess GABA biosynthesis mediates drought tolerance in plants (Yong, et al., 2017). Further studies also revealed that GABA helps in downstream signaling molecules of the stress-related transcriptional factors like *MYB*, *WRKY*, and *ZIPs* may significantly increases drought tolerance in the plants.

5. Role of GABA in stomatal conductance under drought stress

Stomatal regulation through stomatal conductance plays crucial role in the development of drought tolerance in plants. The opening and closing behaviour of the stomata is regulated by stomatal pores through light and dark signaling may facilitate ion and water transport control across the guard cell membrane (Papanatsiou, et al., 2019). Hence, stomatal guard cells responded as a noticeable model system for explicating useful pathways regulating abiotic stress tolerance in plants. GABA has been observed in a variety of plants on stomatal conductance under drought stress (Hasan, et al., 2021). The GABA in association with the ALMT protein family may alter the stomatal conductance (Meyer, et al., 2010). Several ALMT family proteins such as ALTM1, ALTM6, ALTM9, ALTM12, etc. found in the plasma membrane may involved in the regulation of stomatal conductance by malate influx and efflux (Sussmilch, et al., 2019).

It has been further reported that some co-factors bind to control the action of ALMT6 protein by removing ionic calcium from activated protein and have no or negligible effect on the stomatal conductivity. In later reports, it was suggested that cytosolic GABA signaling generated by *GAD2* influences WUE, stomatal opening as well as drought tolerance by negatively controlling the activity of ALMTs (Xu, 2021). On the other hand, ALMT9 assisted the transduction of GABA signaling in the cells under both sufficient water and drought conditions. Therefore, the response of GABA on stomatal closure is not so clear. Thus, the role of GABA signaling in the regulation of stomatal conductance may be caused by light and dark periods.

6. Role of GABA in plants with polyamines under drought conditions

Under drought and other stress conditions, polyamines (PAs) increase simultaneously and play pivotal roles in several physiological processes. PAs generally found in plant cell are free or in conjugated form and synthesized by ornithine and arginine decarboxylation (Hu, et al., 2015). During synthesis of PAs in plant cell, enzyme decarboxylase plays an important role. The polyamines with GABA catabolized under acute stress condition have been documented in several crops (Xiang, et al., 2016). It has been documented by the researchers, the enzyme ADC, ODC and SMADC involved in the production of PAs and other two enzymes CuAo and PAO involved in the breakdown of PAs that may regulate drought stress (Silveira, et al., 2013). Furthermore, it is also documented that GABA accelerates PA biosynthesis in plants to develop tolerance of plants under drought stress. Hence, accumulations of GABA and PAs in plants under water deficit conditions reduces the damage caused by ROS and other oxidative damages to increase tolerance in plants against drought stress (Yang, et al., 2013). In crops like soybean, muskmelon, and fava beans, it has been found that GABA along with PAs reduces oxidative damages in plants and significantly increases tolerance against drought stress.

7. Conclusion

γ- aminobutyric acid (GABA) biosynthesized in plants may control the damage caused by drought and other abiotic stresses. The GABA shunt pathway of the GABA biosynthesis in the plants boosts endogenous GABA as well as antioxidative enzymes in the reduction of ROS generation under drought stress. Furthermore, GABA biosynthesis in plants may also play key role in the stomatal conductance under water deficit conditions. Therefore, overall role of GABA mediated drought stress regulation in plants have been found very useful in drought stress regulation. Thus, exogenous application of GABA in plants under drought stress conditions may increase the GABA supply to the plant cell for reducing the effect of oxidative damage.

References

Akihiro, T., Koike, S., Tani, R., Tominaga, T., Watanabe, S., Iijima, Y., Aoki, K., Shibata, D., Ashihara, H., Matsukura, C. (2008). Biochemical mechanism on GABA accumulation during fruit development in tomato. *Plant Cell Physiol.,* 49:1378–1389.

Clark, S.M., Di Leo, R., Dhanoa, P.K., Van Cauwenberghe, O.R., Mullen, R.T., Shelp, B.J. (2009). Biochemical characterization, mitochondrial localization, expression, and potential functions for an Arabidopsis c-aminobutyrate transaminase that utilizes both pyruvate and glyoxylate. *J. Exp. Bot.*, 60:1743–1757.

Hasan, M.M., Hajar, A.S., Alharby, H.F., Hakeem, K.R. (2018). Effects of magnetized water on phenolic compounds, lipid peroxidation and antioxidant activity of *Moringa* species under drought stress. *J. Anim. Plant Sci.*, 28:803–810.

Hasan, M.M., Skalicky, M., Jahan, M.S., Hossain, M.N., Anwar, Z., Nie, Z.F., Alabdallah, N.M., Brestic, M., Hejnak, V., Fang, X.W. (2021). Spermine: Its Emerging Role in Regulating Drought Stress Responses in Plants. *Cells.,* 10:261.

Hu, X., Xu ,Z., Xu, W., Li, J., Zhao, N., Zhou, Y. (2015). Application of γ-aminobutyric acid demonstrates a protective role of polyamine and GABA metabolism in muskmelon seedlings under Ca $(NO_3)_2$. *Plant Physiol. Biochem.,* 92:1–10.

Jahan, M.S., Wang, Y., Shu, S., Hasan, M.M., El-Yazied, A.A., Alabdallah, N.M., Hajjar, D., Altaf, M.A., Sun, J.S., Guo, S. (2021). Melatonin pretreatment confers heat tolerance and repression of heat-induced senescence in tomato through the modulation of ABA and GA-mediated pathways. *Front. Plant Sci.,* 12:650955

Li, L., Dou, N., Zhang, H., Wu, C. (2021). The versatile GABA in plants. *Plant Signal Behav.* ;16:3.

Meyer, S., Mumm, P., Imes, D., Endler, A., Weder, B., Al-Rasheid, K.A., Geiger, D., Marten, I., Martinoia, E., Hedrich, R. (2010). AtALMT12 represents an R-type anion channel required for stomata movement in Arabidopsis guard cells. *Plant J.*, 63:1054–1062.

Noctor, G., Reichheld, J.P., Foyer C.H. (2018). ROS-related redox regulation and signaling in plants. *Semin. Cell Dev. Biol.,* 80:3–12.

Papanatsiou, M., Petersen, J., Henderson, L., Wang, Y., Christie, J.M., Blatt, M.R. (2019). Optogenetic manipulation of stomatal kinetics improves carbon assimilation, water use, and growth. *Science.,* 363:1456–1459.

Priya, M., Sharma, L., Kaur, R., Bindumadhava, H., Nair, R.M., Siddique, K.H.M., Nayyar H. (2019). GABA (γ-aminobutyric acid), as a thermo-protectant, to improve the reproductive function of heat-stressed mungbean plants. *Sci. Rep.*, 9:7788.

Rashmi, D., Zanan, R., John, S., Khandagale, K., Nadaf, A. (2018). γ-aminobutyric acid (GABA): Biosynthesis, role, commercial production, and applications. *Stud. Nat. Prod. Chem.,* 57:413–452.

Shelp, B.J., Mullen, R.T., Waller, J.C. (2012). Compartmentation of GABA metabolism raises intriguing questions. *Trends Plant Sci.,* 17:57–59.

Silveira, V., de Vita, A.M., Macedo, A.F., Dias, M.F.R., Floh, E.I.S., Santa-Catarina, C. (2013). Morphological and polyamine content changes in embryogenic and non-embryogenic callus of sugarcane. *Plant Cell Tissue Organ Cult.,* 114:351–364.

Steward, F.C. (1949). γ-Aminobutyric acid: A constituent of the potato tuber? *Science.* 110:439–440.

Sussmilch, F.C., Schultz, J., Hedrich, R., Roelfsema, M.R.G. (2019). Acquiring control: The evolution of stomatal signalling pathways. *Trends Plant Sci.,* 24:342–351.

Vanani, F.R., Shabani, L., Sabzalian, M.R., Dehghanian, F., Winner, L. (2020). Comparative physiological and proteomic analysis indicates lower shock response to drought stress conditions in a self-pollinating perennial ryegrass. *PLoS ONE.,* 15:e0234317.

Waseem, M., Nie, N.F., Yao, G.Q., Hasan, M.M., Xiang, Y., Fang, X.W. (2021). Dew absorption by leaf trichomes in *Caragana korshinskii*: An alternative water acquisition strategy to withstand drought in arid environment. *Physiol. Plant.,* 172:528–539.

Xiang, L., Hu, L., Xu, W., Zhen, A., Zhang, L., Hu, X. (2016). Exogenous γ-aminobutyric acid improves the structure and function of photosystem II in muskmelon seedlings exposed to salinity-alkalinity stress. *PLoS ONE.,* 11:e0164847.

Xu, B., Long, Y., Feng, X., Zhu, X., Sai, N., Chirkova, L., Betts, A., Herrmann, J., Edwards, E.J., Okamoto, M., (2021). GABA signalling modulates stomatal opening to enhance plant water use efficiency and drought resilience. *Nat. Commun.,* 12:1952.

Yang, R., Guo, Q., Gu, Z. (2013). GABA shunt and polyamine degradation pathway on γ-aminobutyric acid accumulation in germinating fava bean (Vicia faba L.) under hypoxia. *Food Chem.,* 136:152–159.

Yong, B., Xie, H., Li, Z., Li, Y.P., Zhang, Y., Nie, G., Zhang, X.Q., Ma, X., Huang, L.K., Yan, Y.H. (2017). Exogenous application of GABA improves PEG-induced drought tolerance positively associated with GABA-shunt, polyamines, and proline metabolism in white clover. *Front. Physiol.,* 8:1107.