

# Biofortification of Tomato (*Solanum lycopersicum*) through GABA Technology for Enhanced Stress Tolerance and Nutritional Quality

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Received:- 05 September 2026/ Revised:- 21 September 2026/ Accepted:- 30 September 2026/ Published: 05-10-2026

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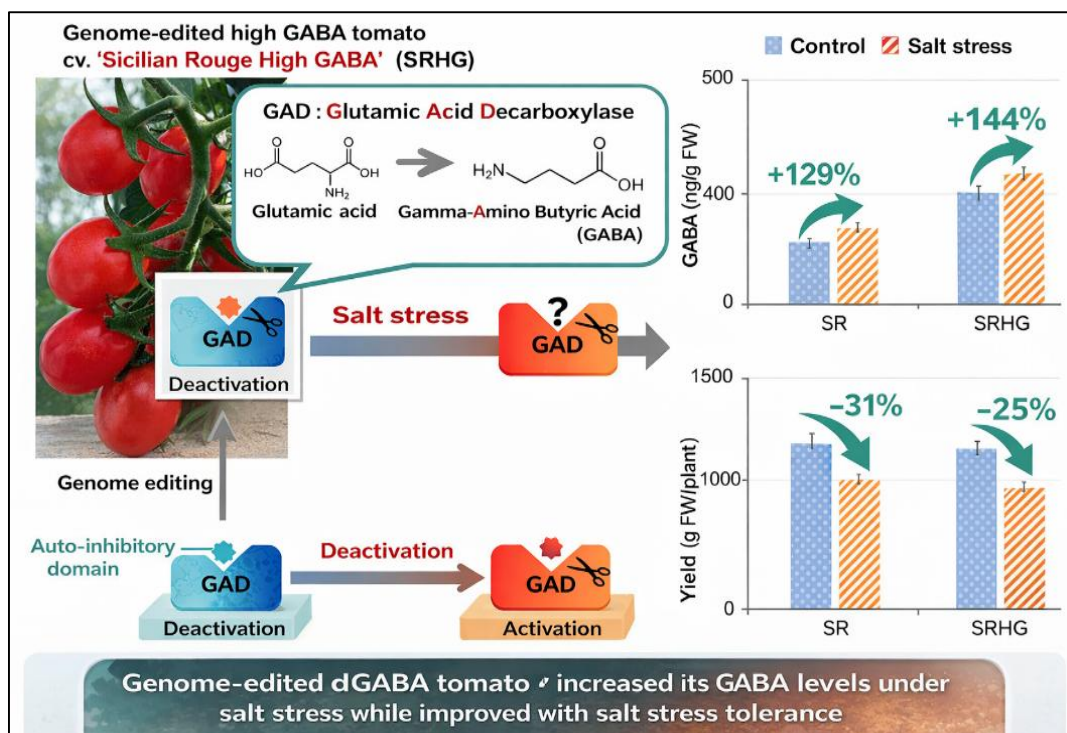
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**Abstract**— Gamma-aminobutyric acid (GABA) technology is a promising biotechnology method for enhancing stress tolerance and nutritional quality in agricultural plants. Although tomato (*Solanum lycopersicum*) is a major vegetable crop consumed worldwide and is rich in vitamins, minerals, and antioxidants, tomato fruits naturally contain low levels of GABA. GABA technology involves the introduction or alteration of genes involved in GABA production using contemporary methods, including genetic transformation, metabolic engineering, and gene editing (CRISPR/Cas9). The enzyme glutamate decarboxylase (GAD) produces GABA from glutamate, and altering the genes governing this enzyme can greatly boost GABA accumulation in tomato fruits. High GABA levels in tomato improve plant resistance to environmental stressors, including salt, drought, and temperature fluctuations, in addition to offering extra health advantages such as decreasing blood pressure and reducing stress in humans. The creation of GABA-enriched tomato aids in the creation of functional foods with higher nutritional content. This technique offers enormous promise for future agriculture and horticulture by enhancing crop quality, productivity, and health benefits, despite several limitations, such as governmental approval, biosafety issues, and public acceptance of genetically modified crops.

**Keywords**— Gamma-aminobutyric acid (GABA), *Solanum lycopersicum*, metabolic engineering, CRISPR/Cas9, functional food.

## I. INTRODUCTION

Gamma-aminobutyric acid (GABA) technology is one of the contemporary biotechnology methods used to enhance crop stress tolerance and nutritional quality. The tomato (*Solanum lycopersicum*) is a major vegetable crop grown all over the world and is frequently consumed by humans. Using genetic engineering and gene-editing methods, scientists have created tomato lines with enhanced GABA content. The introduction of genes or molecular alterations that boost GABA synthesis in tomato plants to enhance yield, stress tolerance, and health benefits is referred to as GABA technology.

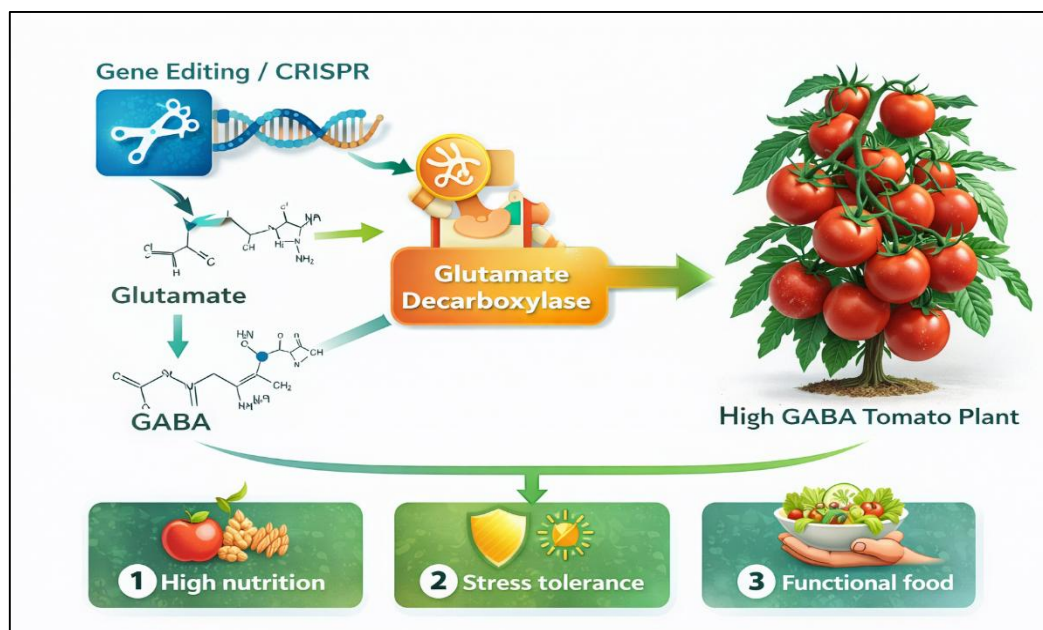


**FIGURE 1: Genome Editing of GAD Enhances GABA Accumulation and Salt-Stress Tolerance in High-GABA Tomato**

## II. WHAT IS GABA AND ITS IMPORTANCE

GABA ( $\gamma$ -aminobutyric acid) is a non-protein amino acid found in both plants and animals. It is crucial for the control of growth, stress response, and metabolism in plants. GABA is well-known for its function in the human neurological system and is linked to decreasing stress and blood pressure. GABA is found naturally in tomato, albeit in low amounts. In order for tomato to become functional foods with health advantages, scientists are working to improve its concentration using biotechnology.

**Gene Editing / CRISPR → GAD Gene Modified → Glutamate → (Glutamate decarboxylase) → GABA → High GABA Tomato Plant → 1-High nutrition 2-Stress tolerance 3-Functional food**



**FIGURE 2: CRISPR/Cas-Mediated Gene Editing for the Development of High-GABA Tomato with Enhanced Nutritional and Stress-Tolerance Traits**

GABA is found naturally in tomato, albeit in low amounts. In order for tomato to become functional foods with health advantages, scientists are working to improve its concentration using biotechnology.

### III. CONCEPT OF GABA TECHNOLOGY IN TOMATO

GABA technology mainly involves:

- 1) Gene editing (CRISPR/Cas9)
- 2) Genetic transformation
- 3) Mutation breeding
- 4) Metabolic engineering

These techniques alter the genes that produce GABA, particularly those linked to the enzyme glutamate decarboxylase (GAD), which transforms glutamate into GABA.

Important genes such as *SIGAD2* and *SIGAD3* have been identified by scientists, and tomato fruits produce more GABA when these genes are edited.

### IV. METHODS USED FOR GABA TECHNOLOGY

#### 4.1 Gene Editing Using CRISPR/Cas9

CRISPR/Cas9 is used to modify specific genes that control GABA synthesis.

- Removal of the inhibitory C-terminal region of the GAD enzyme increases GABA levels.
- Some edited tomato lines showed 7–15 times higher GABA content than normal tomato.

#### 4.2 Agrobacterium-mediated Transformation

This technique uses *Agrobacterium tumefaciens* to introduce beneficial genes into tomato plants.

- This method can result in stable inheritance of high-GABA characteristics in future generations.

#### 4.3 Hybrid Breeding with High-GABA Lines

High-GABA hybrid cultivars can be created by crossing genome-edited tomato with regular types without compromising fruit quality.

#### 4.4 Exogenous Application of GABA

GABA applied externally to plants can boost growth and stress tolerance.

- Promotes resistance to salt stress in tomato plants
- Increases plant height and chlorophyll concentration
- Minimizes harm caused by reactive oxygen species

### V. ADVANTAGES OF GABA TECHNOLOGY IN TOMATO

- 1) **Improved nutritional value** – High-GABA tomato may help in reducing hypertension and stress.
- 2) **Better stress tolerance** – GABA increases resistance to salt, drought, and environmental stress.
- 3) **Higher yield stability** – GABA-rich tomato may maintain fruit quality under stress conditions.
- 4) **Functional food development** – These tomato lines can be used as health-promoting food products.

### VI. CHALLENGES AND RESTRICTIONS

- Public apprehension regarding genetically modified crops
- Regulatory approval in several nations
- The high cost of research and development

- The need for biosafety assessment

GABA technology is seen as a potential instrument in contemporary horticulture despite these difficulties.

## VII. CONCLUSION

The application of GABA technology in tomato represents an important advancement in plant biotechnology. Through gene editing, transformation, and breeding techniques, scientists have successfully developed tomato with higher GABA content, improved stress tolerance, and better nutritional value. This technology has the potential to produce functional foods and increase crop productivity, making it an important innovation for future agriculture.

## ACKNOWLEDGEMENT

The authors thank the editorial board of the International Journal of Environmental & Agriculture Research (IJOEAR) for the opportunity to publish this article. This article is compiled from various published literature, books, and online resources. We sincerely thank all the original authors and researchers whose work is referenced in this article. We are also thankful to our colleagues and family members for their encouragement and support in writing this article.

## CONFLICT OF INTEREST

The authors declare that this article has no conflict of interest. This is a literature-based article, and no experimental research work was conducted for this article. No funding was received from any organization for writing this article. The views expressed in this article are solely those of the authors.

## REFERENCES

- [1] Akama, K., Kanetou, J., Shimosaki, S., Kawakami, K., Tsuchikura, S., & Takaiwa, F. (2001). Enhancement of  $\gamma$ -aminobutyric acid content in transgenic plants by expression of glutamate decarboxylase. *Plant Biotechnology*, \*18\*, 123-130.
- [2] Akama, K., & Takaiwa, F. (2007). C-terminal extension of rice glutamate decarboxylase enhances GABA accumulation and stress tolerance. *Plant Biotechnology*, \*24\*, 301-306.
- [3] Bai, P., Wang, J., He, Y., et al. (2024). Exogenous ALA applied on different plant parts promotes tomato fruit quality and GABA synthesis. *Frontiers in Plant Science*, \*15\*, 1359.
- [4] Bouché, N., & Fromm, H. (2004). GABA in plants: Just a metabolite? *Trends in Plant Science*, \*9\*, 110-115.
- [5] Chew, B. L., et al. (2025). Gamma-aminobutyric acid profiling and standardization of in-vitro regeneration protocol in tomato (*Solanum lycopersicum* L.) genotypes. *PMC*, 12723035.
- [6] Ezura, H. (2019). Genome editing in tomato improvement using CRISPR/Cas9 technology. *Plant Physiology and Biochemistry*, \*131\*, 22-28.
- [7] Gramazio, P., Takayama, M., & Ezura, H. (2020). Challenges and prospects of new plant breeding techniques for GABA improvement in crops: Tomato as an example. *Frontiers in Plant Science*, \*11\*, 577.
- [8] Kinnersley, A. M., & Turano, F. J. (2000). Gamma-aminobutyric acid (GABA) and plant responses to stress. *Critical Reviews in Plant Sciences*, \*19\*, 479-509.
- [9] Kinnersley, A. M., & Lin, F. (2000). Receptor modifiers indicate that GABA is a potential modulator of plant growth. *Plant Growth Regulation*, \*32\*, 65-69.
- [10] Li, L., Zhao, Y., McCaig, B. C., Wing, R. A., Wang, J., & Whittaker, A. L. (2018). CRISPR/Cas9-mediated genome editing for improving nutritional quality in tomato. *Plant Cell Reports*, \*37\*, 1-12.
- [11] Li, J., et al. (2023). Synergistic effects of gamma-aminobutyric acid and melatonin on seed germination and cadmium tolerance in tomato. *Plant Physiology and Biochemistry*, \*195\*, 112-125.
- [12] Li, Y., et al. (2025). Transcriptomic insights into GABA accumulation in tomato via CRISPR/Cas9-based editing of SIGAD2 and SIGAD3. *Genes*, \*16\*(7), 744.
- [13] Malekzadeh, P., Khara, J., & Farshian, S. (2014). Protective effect of  $\gamma$ -aminobutyric acid against chilling stress during reproductive stage in tomato plants. *Frontiers in Plant Science*, \*12\*, 1234.
- [14] Nonaka, S., Arai, C., Takayama, M., Matsukura, C., & Ezura, H. (2017). Efficient increase of GABA content in tomato fruits by targeted mutagenesis. *Scientific Reports*, \*7\*, 7057.
- [15] Nonaka, S., Arai, C., Takayama, M., et al. (2017). Efficient increase of  $\gamma$ -aminobutyric acid (GABA) content in tomato fruits by targeted mutagenesis. *Scientific Reports*, \*7\*, 7057.
- [16] Ramesh, S. A., Tyerman, S. D., Gilliam, M., & Xu, B. (2017). Gamma-aminobutyric acid signaling in plants. *Trends in Plant Science*, \*22\*, 550-560.
- [17] Ramesh, S. A., et al. (2015). GABA signalling modulates plant growth by directly regulating the activity of plant-specific anion transporters. *Nature Communications*, \*6\*, 7879.

- [18] Ramos, R., et al. (2023). Antioxidant properties,  $\gamma$ -aminobutyric acid (GABA) content, and physicochemical characteristics of tomato cultivars. *Agronomy*, \*11\*(6), 1204.
- [19] Saito, T., Matsukura, C., Sugiyama, M., et al. (2008). Screening for  $\gamma$ -aminobutyric acid (GABA)-rich tomato varieties. *Journal of the Japanese Society for Horticultural Science*, \*77\*(3), 242-250.
- [20] Seifikalhor, M., et al. (2020). Gamma-aminobutyric acid confers cadmium tolerance in Arabidopsis and tomato by modulating antioxidant defense. *Ecotoxicology and Environmental Safety*, \*191\*, 110200.
- [21] Singh, P., et al. (2025). GABA mitigates NaCl toxicity by enhancing photosynthesis, chloroplast structure, and redox balance in salt-tolerant and sensitive tomato varieties. *Environmental Science and Pollution Research*, \*32\*, 40140201.
- [22] Sita, K., & Kumar, V. (2020). Gamma-aminobutyric acid: A novel biomolecule to improve plant resistance and fruit quality. *Horticulturae*, \*9\*(5).
- [23] Suzuki, Y., et al. (2026). Enhanced endogenous GABA biosynthesis modifies fruit production and GABA accumulation in a medium-sized tomato cultivar under salt stress. *Plant-Environment Interactions*, \*7\*(1).
- [24] Takayama, M., & Ezura, H. (2015). How and why tomato fruit size and shape vary. *Horticulture Research*, \*2\*, 15014.
- [25] Takayama, M., Koike, S., Kusano, M., et al. (2015). Tomato glutamate decarboxylases SlGAD2 and SlGAD3 regulate GABA levels in fruits. *Plant and Cell Physiology*, \*56\*(8), 1497-1507.
- [26] Ullus, S. (2021). GABA affects physicochemical characteristics of tomato fruits during postharvest storage. *Journal of Agricultural Sciences*, \*27\*(4).
- [27] Wang, L., et al. (2025). Molecular mechanism of exogenous GABA in regulating salt tolerance in tomato (*Solanum lycopersicum* L.). *International Journal of Molecular Sciences*, \*26\*(10), 4987.
- [28] Wu, Q., et al. (2020). Gamma-aminobutyric acid (GABA) alleviates salt damage in tomato by modulating Na<sup>+</sup> uptake, the GAD gene, amino acid synthesis and ROS metabolism. *BMC Plant Biology*, \*20\*, 1-20.