

Mitigation of drought stress effects on sweet potato plants by application of γ -Aminobutyric acid

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Abstract

The goal of the present study is to examine the role of γ -aminobutyric acid (GABA) at control, 0.5, and 1 mM L⁻¹ in reducing the effects of drought stress and enhancing field performance on sweet potato (*Ipomoea batatas* (L.) Lam. var. *batatas*) under 2 irrigation regimes (50% and 70% exhaustion of available soil water). The results showed that, the relative water content (RWC) was decreased by 8%, nutrient uptake such as N, P, K and Ca by 39%, 23%, 9% and 11% respectively and yield (by 46%). However, osmolyte content (free amino acids FAA, soluble sugars, and proline), lipid peroxidation (MDA) and activity of peroxidase (28%) showed significant increases due to water stress. In sweet potato plants, application of GABA (particularly at 1 mM L⁻¹) showed a partial normalization of drought effects. The 1 mM dose was further active than 0.5 mM L⁻¹ in enhancing SPAD rate, dry matter, and carotene content. Furthermore, the 1 mM L⁻¹ dose enhanced plant growth, water status, osmotic adjustment, antioxidant defence, and nutritional acquisition. The 1 mM dose was more effective than 0.5 mM L⁻¹ in alleviating drought effects, leading to better yield and enhanced physiological reactions. In general, application of GABA seems to be a useful priming method for semiarid sweet potato plants in reducing the negative effects of drought stress. Significant reductions in plant growth and leaf relative water content and total soluble solids were caused by water stress in sweet potato plants. Exogenous foliar application of GABA at 1 mM L⁻¹ enhanced osmotic adjustment, water plant status, and antioxidant defence systems, also improved nutrient uptake in sweet potato plants grown under drought stress.

Keywords: antioxidant enzymes; carotenoids; GABA; *Ipomoea batatas*.; water deficit

Introduction

Water deficit or drought stress is an important factor that limits the growth and production of several plants (Abd El-Gawad *et al.*, 2021; AlKahtani *et al.*, 2021; Arafa *et al.*, 2021; Elkelish *et al.*, 2021; Abdelaal *et al.*, 2022). In many parts of the world, it seriously threatens food security (Alshammari *et al.*, 2024a). Furthermore, the rate of evapotranspiration can rise sharply due to frequent climate change and global warming (Yang *et al.*, 2019). In this regard, it is known that over 50% of arable lands will experience severe issues due to drought stress by 2050 (Kasim *et al.*, 2013). Drought stress can be involved in a wide spectrum of complex changes in morphological characters (EL Sabagh *et al.*, 2018; Khaffagy *et al.*, 2022), physiological characteristics (Alharbi *et al.*, 2025; Abdou *et al.*, 2023; Hafez *et al.*, 2020), and biochemical features in many plants (Abdelaal *et al.*, 2024; Alshammari *et al.*, 2024b). These factors include limiting the electron transport chain (ETC), stomatal conductance, transpiration rate, CO₂ fixation, and nutrient transfer resulting in a major disruption of respiration and photosynthesis (Carminati and Javaux, 2020; Alshammari *et al.*, 2024b). In addition, the hormonal balance, cell membrane's structure and dysfunction were negatively affected by drought stress. Increased levels of reactive oxygen species (ROS), which result in oxidative damage to all organelles, are generally linked to these detrimental effects (Ibrahim *et al.*, 2021).

A neurotransmitter that is non-proteinogenic, γ -aminobutyric acid (GABA) is found in a wide variety of living organisms, including microbes, mammals, insects, worms, and plants (Gou *et al.*, 2012) in the wake of its initial discovery in *Solanum tuberosum*. Over the past few decades, research has elucidated the function of GABA in signalling pathways, gene expression, and the induction of antioxidant defence systems in response to various stress factors (Shelp *et al.*, 2012). Additionally, it can function as a transient N pool and a cytoplasmic pH regulator. According to various papers, GABA signaling is furthermore linked to stress-related transcription factors (WRKY, MYB, and bZIP), the regulation of Ca signaling, and regulating of redox homeostasis. GABA has been shown in several earlier studies to mitigate the harmful impacts of a variety of abiotic stimuli, such as water stress, salinity, heat stress, and heavy metals (Wang *et al.*, 2014). Under water deficiency, GABA can function as a protective agent by preserving the stability of the cell membrane and the relative water content (RWC) in plants, (Wang *et al.*, 2009). Sweet potato is one of the most important crops in the world because it contains a large amount of carbohydrates in its roots, which act as a principal energy source used for living organisms (Zhang *et al.*, 2025). It is one of the important vegetable crops in the tropics and subtropics, it belongs to Convolvulaceae family. The annual cultivated area for sweet potato in Egypt is about 14.775 thousand hectares and is used for nutrition after boiling or it may be used in making sweets, as a type of pie, or preserved in cans (FAO, 2022). Some potato varieties are also used in the starch and alcohol extraction industry. In Egypt, water stress is one of the primary physiological constraints that limit potato production each year. Irrigation management with low water consumption is one of the major challenges for researchers worldwide, as the plant's photosynthetic capacity is highly sensitive to water deficit conditions. The researchers resorted to reducing the harmful impacts of water deficiency in the different plants by using signalling molecules, including GABA, nitric oxide (NO) and folic acid, which had a remarkable effect on improving growth and productivity under conditions of water deficiency. Even though the role of GABA in mitigation abiotic stress has been described in respective crops, its efficacy in sweet potato, remarkably under drought stress conditions, has not been evidently researched. This understanding gap limits the progress of strategies to improve sweet potato tolerance to drought stress.

Therefore, the present research aims to study the physiological, morphological and productive response of the sweet potato crop under conditions of drought (water stress) to foliar spraying of GABA during the different stages of plant growth. Unlike earlier investigates on other crops, this study presents the first evaluation of GABA application in sweet potato crop under water deficit, weight its potential as a practical approach for enhancing crop growth under drought stress conditions.

Materials and Methods

The field study was conducted at the experimental farm, Ain Shams University's Faculty of Agriculture, Shubra El-Kheima city (30.113844° N, 31.247597° E) Qalyubiyya governorate, Egypt during 2022 and 2023 seasons, to investigate the impact of γ -aminobutyric acid (GABA) (molecular weight of 103.12 g mol⁻¹) on sweet potato (*Ipomoea batatas* L.) Lam. var. *batatas*) 'Bio Guard' under water stress (drought) conditions.

Cuttings of sweet potato 'Bio Guard' were sown on the 13 May 2022 and 2023 seasons. The experimental plot was 8 m² and had two rows, each measuring 5 m in length and 0.8 m in width. On one side, the plants were spaced 25-30 cm apart, and the border between treatments was 1 m wide.

Experimental design and treatments

Irrigation applied at 50% and 70% of accessible soil water was depleted, agreeing to nearly 100% and 60% of water requirement of the crop, correspondingly. Applying 50% depletion level was respected the optimal irrigation (control), 70% depletion simulated water limits (drought stress conditions). The GABA was applied as a foliar application three times (40, 61, and 82 days from sowing) at 3 levels: control (sprayed using water only), 0.5 and 1 mM L⁻¹. The experiment was arranged in a split plot design with three replications. The irrigation treatments were allocated in the main plots, foliar applications were in the sub plots (three separate experiments).

Fertilizer and soil management

Phosphorus was added in the form of (super phosphate) (15% P₂O₅) at 714 kg ha⁻¹ during the soil preparation. After planting, fertilization was done with about 71.4 kg ha⁻¹ N and 238 kg ha⁻¹ K₂O as soil application in three doses, the first application was done after 1 month from planting, about 35.7 kg N were added (ammonium sulphate fertilizer was used for this) and 59.5 kg K₂O (about 123.76 kg potassium sulphate (48% K₂O)); the second was done after 1 month from the first dose, about 35.7 kg N were added (ammonium nitrate) and 119 kg K₂O. The third one was carried out after 2-3 week from the second addition, about 59.5 kg K₂O was added (about 123.76 kg potassium sulphate (48% K₂O)).

Irrigation management and harvest

Forty days after cultivation, the irrigation treatments were initiated and continued until 3 weeks before the roots harvest, when irrigation was stopped. Harvesting date was done once the roots were matured after 105-120 days from sowing (yellowing and drying of leaves).

Soil sampling and analysis

Three random samples of clay loam soil were collected from the experimental site by an Auger T-Handle at depths of 0-25 and 25-50 cm from soil surface Prior to soil preparation, field capacity, and soil water availability for both seasons were determined (Table 1).

Table 1. Analysis of the experimental soil during the 2022 and 2023 seasons

Depth of soil	2022			2023		
	FC (%) [*]	Wilting point (%)	Available water (%)	FC (%)	Wilting point (%)	Available water (%)
0-25	48.20	24.10	24.10	47.50	23.75	23.75
25-50	46.80	23.40	23.40	45.40	22.70	22.70
Average	47.50	23.75	23.75	46.45	23.22	23.22

^{*}FC: Field capacity

Hydrophysical properties determination

Field Capacity (FC): The soil moisture content is estimated after excess water has been drained from the soil. This typically takes several days after irrigation.

Wilting Point (WP): Determine the moisture content at which plants cannot absorb water through the roots and the leaves wilt. This is typically measured at a soil water pressure of 15 bars.

Available Water Capacity (AWC): Estimated as the difference between the water content at field capacity and the wilting point. This represents the amount of water readily available for absorption by plant roots.

Vegetative characteristics

To study the number of branches per plant, plants were randomly selected from three replicates at 70 days after planting. Moreover, for each experimental plot, five plants were used to record the following: number of leaves per plant, fresh weight of leaves and stems per plant, and dry weight of leaves and stems per plant. The fourth enlarged, fully developed upper leaf of each of the 21 plants in the middle of the two rows of each plot were used to calculate chlorophyll reading (SPAD). The Minolta SPAD-502 digital chlorophyll meter (Minolta CO., LTD, Japan) was utilized. The relative values for chlorophyll content were derived from the SPAD data.

Roots characteristics

Roots of 10 plants were taken from each plot; average fresh and dry weight of roots per plant and per hectare were determined. Marketable roots of experimental plot and hectare were recorded.

Biochemical characteristics

Proline content was determined utilizing the method of acid-ninhydrin reagent as specified by (Bates *et al.*, 1973).

Total phenolic: In an alkaline medium, phenols react with the oxidizing agent phosphomolybdic acid in Folin-Ciocalteu reagent to form a blue-colored complex known as molybdenum blue, which is detected spectrophotometrically at 650 nm (Malik and Singh, 1980) utilizing the spectrophotometer model CT-2200, E-ChromTech Co., Ltd, Taiwan.

Free amino acids were assayed using the method of Hamilton *et al.* (1943); one milliliter of 10% pyridine and one milliliter of 2% ninhydrin solution were added to one milliliter of each sample extract. The determination was done using spectrophotometer at 570 nm. To measure the total soluble solids (TSS), a hand refractometer was used (HR-190, OPTIKA, Ponteranica, Italy). TSS were measured using anthrone-sulfuric acid reagent as described by (Plummer 1987). According to Bradford (1976), total soluble protein was determined.

Determination of mineral nutrients

Hydrogen peroxide and sulfuric acid were used after grind to digest the dry leaves. N, P, K, and Ca mineral concentrations in leaves were measured using the method of (Cottenie *et al.*, 1982). The Kjeldahl method (Distillation unit F30200183, UDK127, Europe), was used to determine Nitrogen content. However, Phosphorus was determined using the colorimetric method by UV/VIS spectrophotometer. Potassium was determined by a flame photometer (model MDPFP7, UK). Meanwhile, Ca was determined by atomic absorption spectrophotometry (utilizing the spectrophotometer model CT-2200, E-ChromTech Co.,Ltd, Taiwan).

Peroxidase activity and lipid peroxidation (MDA)

Leaves of sweet potato (0.5 g) were homogenised in 4 mL 0.1 M buffer (pH 7.0) containing 1% (w:v) polyvinylpyrrolidone (PVP) and 0.1 mM EDTA. The solution was centrifuged for 15 minutes at 10,000 rpm, and supernatant obtained was used as an enzyme extract, every step was carried out at between 0 and 4 °C. Peroxidase activity (POX, EC 1.11.1.7) was examined using the methods of Dias and Costa (1983) as $\text{min}^{-1} \text{mg}^{-1}$ protein. According to (Heath and Packer 1968), lipid peroxidation was quantified by measuring malondialdehyde (MDA).

Statistical analysis

Data of the two seasons were arranged and statistically analyzed using Mstastic (average two seasons). The comparison among means of the different treatments was determined, as illustrated by Snedecor and Cochran (1982).

Results

Data displayed in Tables 2 and 3 show the influence of irrigation at 50% and 70% depletion of field capacity and foliar application of γ -aminobutyric acid (GABA) on leaves number, fresh and dry weight of leaves, and fresh and dry weight of stems and Soil-Plant Analysis Development (SPAD) reading. In general, the vegetative growth of sweet potato responded positively to irrigation levels. Irrigation at depletion of 50% field capacity increased number of leaves, fresh and dry weight of leaves, and fresh and dry weight of stems and SPAD reading, in the both seasons, when compared to the other treatments. This could be owing-to the role of water in photosynthetic assimilates, which led to an increase in leaves number. Respecting GABA's foliar application, the information gathered indicated that the application on the leaves of GABA with concentration 1 mM L^{-1} increased leaves number, fresh and dried weight of leaves, and stems fresh weight as well as SPAD reading in both seasons and the foliar application of GABA with concentration 0.5 or 1 mM L^{-1} increased stem dry weight in both seasons.

Table 2. Effect of foliar application of GABA on chlorophyll reading (SPAD value), leaves fresh and dry weight of sweet potato plants grown under two levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L^{-1})	Chlorophyll reading (SPAD)		Leaves fresh weight (g)		Leaves dry weight (g)	
		2022	2023	2022	2023	2022	2023
Control (70%)	0	39.31 bc	39.83 b	188.86 c	181.91 c	42.99 b	31.00 b
	0.5	40.25 b	39.66 b	213.25 b	208.07 b	46.47 a	34.99 a
	1	41.91 a	41.40 a	231.50 a	223.94 a	46.48 a	33.85 a
	Mean	40.49 A	40.30 A	211.21 A	204.64 A	45.31 A	33.28 A
Water stress (50%)	0	36.08 d	35.99 d	112.06 e	108.37 f	29.83 d	21.66 d
	0.5	38.39 c	37.97 c	141.55 d	143.71 e	33.47 c	25.45 c
	1	40.05 b	40.56 ab	193.78 c	193.54 d	40.67 b	30.61 b
	Mean	38.17 B	38.17 B	149.13 B	148.54 B	34.65 B	25.91 B
GABA (mM L^{-1})	0	37.69 C	37.91 C	150.46 C	145.14 C	26.33 C	26.33 C
	0.5	39.32 B	38.81 B	177.40 B	175.89 B	30.22 B	30.22 B
	1	40.98 A	40.98 A	212.64 A	208.74 A	32.23 A	32.23 A
LSD ₀₅	Irr.	1.404	1.955	5.53	3.4455	1.079	2.1579
	γ .	0.992	0.67	6.27	6.2	1.77	1.35
	Irr * γ .	2.20	0.95	8.872	8.775	2.507	1.909

Values by different letters in the same column are significantly different at $P \leq 0.05$

Table 3. Effect of foliar application of GABA on stem fresh and dry weight and leaves number of sweet potato plants grown under levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L ⁻¹)	Stem fresh weight (g)		Stem dry weight (g)		No. of leaves / plant	
		2022	2023	2022	2023	2022	2023
Control (50%)	0	185.05 bc	181.62 b	40.70 ab	40.30 ab	88.00 c	87.56 b
	0.5	189.56 ab	186.68 a	41.73 a	37.90 ab	91.56 ab	92.15 a
	1	192.28 a	187.63 a	42.33 a	42.81 a	92.89 a	91.93 a
	Mean	188.96 A	185.31 A	41.59 A	40.32 A	90.81 A	90.54 A
Water stress (70%)	0	155.77 e	152.90 d	26.89 d	24.75 c	71.11 e	70.07 d
	0.5	168.22 d	160.84 c	37.13 c	38.20 ab	82.67 d	80.44 c
	1	182.56 c	180.77 b	38.05 bc	36.88 b	90.22 b	90.37 a
	Mean	168.85 B	164.84 B	34.03 B	33.27 B	81.33 B	80.30 B
GABA (mM L ⁻¹)	0	170.41 C	167.26 C	33.80 B	32.50 B	79.56 C	78.81 C
	0.5	178.89 B	173.76 B	39.43 A	38.04 A	87.11 B	86.30 B
	1	187.42 A	184.20 A	40.19 A	39.85 A	91.56 A	91.15 A
LSD05	Irr.	11.685	4.69	0.3576	6.676	1.69	1.49
	γ.	3.56	2.3676	2.027	3.4997	1.5	1.40
	Irr * γ.	5.037	3.348	2.867	4.949	2.13	1.986

Values by different letters in the same column are significantly different at $P \leq 0.05$

Regarding the interactions, the studied combination between irrigation and the application of GABA indicated that plants irrigated after depletion of 50% field capacity and foliar application of 1 mM L⁻¹ GABA showed the highest SPAD reading and leaf fresh weight in both seasons and the application of GABA with concentration 0.5 mM L⁻¹ or 1 mM L⁻¹ increased leaf number, fresh and dry weight of stems as well as leaf dry weight in both seasons. While the highest results under drought were foliar application of 1 mM L⁻¹ GABA in each of leaf number, leaf fresh and dry weight, stem fresh weight and SPAD reading and the application of GABA with concentration 0.5 mM or 1 mM L⁻¹ increased stem dry weight in the 2 seasons.

Leaf and tubers chemical and biochemical analysis

Data presented in Tables (4-7) show the influence of irrigation at different percentages of field capacity, foliar application of GABA on chemical analyses. In general, chemical analyses of sweet potato responded positively to irrigation at different percentages of water depletion. Irrigation at depletion of 50% field capacity resulted in the highest values of N, K, P, Ca (Table 4), leaf relative water content (LRWC), dry matter of tubers and carotene (tubers) compared to the other irrigation treatments during the both seasons (Table 5). However, irrigation at depletion of 70% field capacity gave the highest values of proline, total phenolic, free amino acids (Table 6), total soluble solids (tubers), total sugar, peroxidase activity and MDA (leaves) compared to the other irrigation treatments during the both seasons. The data showed that foliar usage of GABA at 1 mM L⁻¹ pointedly improved proline level, total phenolics content, FAA, N, P, K, Ca, dry matter, leaf relative LRWC, total sugars content, peroxidase enzyme activity, and carotene content under both seasons (Table 7). In contrast, the 0 mM GABA dose (control) established the greatest MDA content across two seasons. Remarkably, dose with 0.5 mM L⁻¹ GABA showed a boost in total TSS through the first season. In terms of the interactions, the studied combination between irrigation at different percentages and the application of GABA indicated that plants irrigated after depletion of 50% field capacity and foliar application of 1 mM L⁻¹ GABA showed the highest N, P, K, Ca, dry matter %, LRWCB and carotene in both seasons, While the best results under drought were foliar application of 1 mM L⁻¹ GABA in each of proline, total phenolic, free amino acids, TSS, total sugar and peroxidase activity and the foliar application of GABA with concentration 0 mM increased MDA in the 2022 seasons.

Table 4. Effect of foliar application of GABA on N, K, P and Ca % of dry weight of sweet potato leaves grown under two levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L ⁻¹)	N (%)		K (%)		P (%)		Ca (%)	
		2022	2023	2022	2023	2022	2023	2022	2023
Control (50%)	0	2.60 c	2.92 c	1.59 c	1.55 c	1.33 c	1.39 b	1.03 c	1.07 c
	0.5	2.78 b	3.16 b	1.63 b	1.64 b	1.43 b	1.43 b	1.10 b	1.12 b
	1	3.11 a	3.42 a	1.69 a	1.76 a	1.48 a	1.53 a	1.18 a	1.23 a
	Mean	2.83 A	3.17 A	1.64 A	1.65 A	1.41 A	1.45 A	1.11 A	1.14 A
Water stress (70%)	0	1.72 f	1.82 f	1.39 f	1.36 f	0.82 f	0.94 d	0.92 d	0.95 d
	0.5	2.03 e	2.23 e	1.45 e	1.43 e	0.97 e	1.07 c	1.02 c	1.03 c
	1	2.34 d	2.60 d	1.54 d	1.48 d	1.08 d	1.09 c	1.03 c	1.05 c
	Mean	2.03 B	2.21 B	1.46 B	1.42 B	0.96 B	1.03 B	0.99 B	1.01 B
GABA (mM L ⁻¹)	0	2.16 D	2.37 C	1.49 C	1.46 C	1.07 C	1.16 C	0.98 C	1.01 C
	0.5	2.41 B	2.70 B	1.54 B	1.53 B	1.20 B	1.25 B	1.06 B	1.08 B
	1	2.72 A	3.01 A	1.61 A	1.62 A	1.28 A	1.31 A	1.11 A	1.14 A
LSD05	Irr.	0.09	0.02	0.027	0.005	0.033	0.036	0.099	0.086
	γ.	0.06	0.05	0.009	0.015	0.031	0.034	0.029	0.035
	Irr * γ.	0.09	0.07	0.013	0.014	0.043	0.048	0.042	0.05

Values by different letters in the same column are significantly different at P ≤ 0.05

Table 5. Effect of foliar application of GABA on dry matter of tubers, leaf relative water content (LRWC %) (leaves) and total soluble solids by degrees Brix (tubers) of sweet potato plants grown under two levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L ⁻¹)	Dry matter (%)		LRWC (%)		TSS (Brix)	
		2022	2023	2022	2023	2022	2023
Control (50%)	0	23.4 bc	23.4 ab	75.32 c	77.92 c	7.9 d	8.6 d
	0.5	24.8 ab	24.6 a	76.21 b	78.98 b	8.8 c	9.4 c
	1	25.1 a	24.5 a	77.84 a	79.93 a	9.2 c	9.8 bc
	Mean	24.4 A	24.2 A	76.45 A	78.94 A	8.6 B	9.3 B
Water stress (70%)	0	19.5 d	19.4 d	71.29 e	72.52 e	10.8 a	11.4 a
	0.5	20.3 d	20.5 cd	74.37 d	76.33 d	10.6 a	10.9 a
	1	22.1 c	21.8 bc	76.77 b	79.02 b	10.0 b	10.3 b
	Mean	20.6 B	20.6 B	74.14 B	75.95 B	10.5 A	10.9 A
GABA (mM L ⁻¹)	0	21.4 B	21.4 B	73.30 C	75.22 C	9.4 B	10.0
	0.5	22.5 AB	22.6 AB	75.29 B	77.65 B	9.7 A	10.2
	1	23.6 A	23.1 A	77.30 A	79.47 A	9.6 AB	10.1
LSD05	Irr.	1.4	0.774	0.8176	0.317	0.863	1.1
	γ.	1.13	1.27	0.342	0.3298	0.323	NS
	Irr * γ.	1.59	1.8	0.584	0.466	0.457	0.64

Values by different letters in the same column are significantly different at P ≤ 0.05

Table 6. Effect of foliar application of GABA on proline total phenolic and free amino acids of sweet potato leaves grown under two levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L ⁻¹)	Proline ($\mu\text{g g}^{-1}$ F.Wt)		Total phenolic (Mg g ⁻¹ F.Wt)		Free amino acids ($\mu\text{g g}^{-1}$ F.Wt)	
		2022	2023	2022	2023	2022	2023
Control (50%)	0	189 f	202 d	12.6 f	12.9 c	472 c	452 c
	0.5	229 e	249 c	13.3 e	13.5 c	519 d	530 d
	1	268 d	278 c	13.9 d	14.5 b	526 d	544 d
	Mean	229 B	243B	13.3 B	13.6 B	506 B	509 B
Water stress (70%)	0	484 c	567 b	14.2 c	15.0 b	1149 c	1089 c
	0.5	528 b	616 a	14.7 b	15.7 a	1222 b	1162 b
	1	653 a	643 a	15.2 a	16.0 a	1253 a	1193 a
	Mean	555 A	609 A	14.7 A	15.6 A	1208 A	1148 A
GABA (mM L ⁻¹)	0	337 C	384 B	13.4 C	14.0 C	810 C	770 C
	0.5	379 B	433 A	14.0 B	14.6 B	870 B	846 B
	1	460 A	460 A	14.6 A	15.3 A	890 A	869 A
LSD05	Irr.	23	52	0.378	1.123	98.46	14.9
	γ.	12	31	0.09	0.479	7.97	18.3
	Irr * γ.	16	44	0.128	0.678	11.28	25.8

Values by different letters in the same column are significantly different at $P \leq 0.05$

Table 7. Effect of foliar application of GABA on total sugar, peroxidase activity, MDA (leaves) and carotene (tubers) of sweet potato plants grown under two levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L ⁻¹)	Total sugar (mg g ⁻¹ F.Wt)		Peroxidase activity (unit.mg ⁻¹ protein)		MDA ($\mu\text{mole g}^{-1}$)	Carotene ($\mu\text{g g}^{-1}$)
		2022	2023	2022	2023	2022	2022
Control (50%)	0	21.2f	22.2f	975 e	941 e	0.036 d	233.37 c
	0.5	21.8e	23.1e	1532 d	1635 d	0.032 e	276.37 b
	1	22.4d	23.7d	1684 d	1650 d	0.026 f	374.91a
	Mean	21.8B	23.0B	1397 B	1409 B	0.031 B	294.88 A
Water stress (70%)	0	24.7c	26.3c	2660 c	2833 c	0.067 a	142.78 f
	0.5	25.3b	26.7b	3202 b	3087 b	0.054 b	172.90 e
	1	26.8a	28.8a	3551 a	3519 a	0.046 c	223.30 d
	Mean	25.6A	27.3A	3138 A	3146 A	0.056 A	179.66 B
GABA (mM L ⁻¹)	0	22.9C	24.3C	1817 C	1887 C	0.051 A	188.07 C
	0.5	23.6B	24.9B	2367 B	2361 B	0.043 B	224.64 B
	1	24.6A	26.2A	2617 A	2584 A	0.036 C	299.10 A
LSD05	Irr.	0.14	0.19	155	143	0.00828	0.5816
	γ.	0.15	0.23	136	88	0.00129	1.353
	Irr * γ.	0.21	0.32	192	125	0.00168	1.914

Values by different letters in the same column are significantly different at $P \leq 0.05$

Yield characteristics

Data presented in Table 8 show the influence of irrigation at different percentages of field capacity depletion, and the application of GABA on yield characteristics. In general, chemical analyses of sweet potato responded positively to irrigation at different percentages. Irrigation at depletion of 50% field capacity resulted

in the highest values of yield (plot and hectare), marketable yield (hectare) compared to the other irrigation treatments during the both seasons. The obtained data showed that the application of GABA with concentration 1 mM L⁻¹ increased yield per plot and hectare and marketable yield per hectare in the both seasons. The studied combination between irrigation at different percentages and the application of GABA indicated that plants irrigated after depletion of 50% field capacity and the application on the leaves of 1 mM L⁻¹ GABA showed the highest yield per plot and hectare and marketable yield per hectare in the two seasons.

Table 8. Effect of foliar application of GABA on yield per plot (kg) and hectare (ton) and marketable yield/hectare(ton) of sweet potato plants grown under two levels of irrigation (50% and 70% field capacity) in 2022 and 2023 seasons

Irrigation	GABA (mM L ⁻¹)	Yield plot ¹ (kg)		Yield hectare ¹ (ton)		Marketable yield hectare ¹ (ton)	
		2022	2023	2022	2023	2022	2023
Control (50%)	0	19.13b	19.29b	23.90 b	24.10 c	19.13 b	19.29 c
	0.5	20.94a	20.87a	26.18 a	26.08 b	20.94 a	20.87 b
	1	21.57a	21.78a	26.90 a	27.23 a	21.57 a	21.78 a
	Mean	20.55A	20.65A	25.66 A	25.80 A	20.55 A	20.65 A
Water stress (70%)	0	10.96d	10.20d	13.70 d	13.66 e	8.22 e	8.169 f
	0.5	15.29c	15.12c	19.10 c	18.90 d	13.37 d	13.23 e
	1	15.52c	15.42c	19.40 c	19.27 d	15.52 c	15.42 d
	Mean	13.92B	13.58B	17.40 B	17.28 B	12.37 B	12.27 B
GABA (mM L ⁻¹)	0	15.05B	14.75B	18.80 B	18.88 C	13.68 C	13.73 C
	0.5	18.11A	17.99A	22.64 A	22.49 B	17.16 B	17.05 B
	1	18.55A	18.60A	23.15 A	23.25 A	18.55 A	18.60 A
LSD05	Irr.	2.0958	0.9777	2.632	1.242	1.95	0.991
	γ.	0.5067	1.0017	0.632	0.6538	0.491	0.484
	Irr * γ.	0.7165	1.4165	0.8939	0.9246	0.694	0.685

Values by different letters in the same column are significantly different at P ≤ 0.05

Discussion

Significant obstacles to crop sustainability and yield are posed by water stress in semi-arid cultivation soils (Paul *et al.*, 2019). Additionally, it seems that temperature, solar radiation, and soil composition are crucial in controlling crop moisture stress index (CMSI), plant growth (shoot-root ratio), and other physiological parameters in plant organs (Li *et al.*, 2017). The goal of this study was to investigate how GABA helps sweet potato plants cope with water stress. GABA has been shown to be an efficient stress-priming molecule. Previous research indicates that GABA plays a part in promoting water deficit stress tolerance in perennial ryegrass (*Lolium perenne*), bentgrass (*Agrostis stolonifera*) and bread wheat (Li *et al.*, 2018). Application of GABA has been reported to modulate the antioxidative defence system, relative water content, and field performance under drought conditions (Jurkonienė *et al.*, 2025).

In the current study, treating water-stressed sweet potatoes with GABA led to decrease lipid peroxidation (MDA content), increase fresh and dry weight of shoot, and RWC. It has also been noted that when GABA is supplemented during a water stress, leaf area increases. Thus, giving sweet potato plants under drought stress 1 mM L⁻¹ GABA is probably going to help with osmotic balance (osmolyte buildup). It has previously been documented that musk melon plants under stress from salinity and alkalinity experience a reduction in membrane lipid peroxidation due to GABA (Ge *et al.*, 2012). In white clover plants, GABA treatment resulted in decreased lipid peroxidation, increased tissue water content, and decreased leaf wilting. According to the current research, applying GABA to these plant growth parameters under well-watered

conditions appears to have a negligible impact. In sweet potatoes, the three osmolytes soluble sugars, proline, and free amino acids accumulate in response to water stress. The available data is consistent with past findings about GABA's function in controlling osmolytes, such as soluble sugars and proline (Yong *et al.*, 2017). Furthermore, osmolyte levels in the control group of plants (that receive enough watering) are slightly altered by GABA. Thus, giving plants under water stress GABA treatment especially at 1 mM L⁻¹ is beneficial in fostering osmotic tolerance. When GABA was applied to drought-stressed plants, endogenous GABA accumulated more and proline metabolism and GABA-shunt pathway enzymes were positively upregulated (Yong *et al.*, 2017). Our current findings are supported by previous research on the positive modulation of proline metabolism induced by GABA. In water-stressed sweet potato, GABA treatment (0.5 and 1 mM L⁻¹) causes a spike in proline accumulation (present work). The current results show that when sweet potato plants under water stress receive GABA supplementation, there is a little increase in the accumulation of soluble carbohydrates. Therefore, it is anticipated that GABA signalling during water stress could control the metabolism of carbohydrates in the current investigation.

Redox homeostasis is known to result from both non-enzymatic and enzymatic antioxidative defence being triggered by a drought stress (AlKahtani *et al.*, 2021; Alkhateeb *et al.*, 2024; Abd-El-Aty *et al.*, 2024). Our findings show that POX activity was significantly increased under drought stress. An analogous pattern was noted for the enzyme, indicating their combined function in controlling sweet potato resistance to drought stress. The antioxidant enzyme's activity is positively upregulated when GABA is applied exogenously. The current study on sweet potato plants shows that lipid peroxidation decreased along with GABA-induced upregulation of antioxidant enzymes.

Drought stress limits nutrient translocation in plant organs and has a negative impact on nutrient uptake and growth characters (Abdelal *et al.*, 2021; Alharbi *et al.*, 2025; Alshammari *et al.*, 2024a and b). In the current study, the content of N, P, K, and Ca in sweet potato leaves significantly decreased because of drought stress. Previous results indicated that the reduction in N-uptake protein activity linked to drought stress, which is consistent with the findings of Bista *et al.*, (2018). Using GABA led to enhance the absorption of N in the leaves of sweet potato plants under drought stress. In nutrient-stressed Arabidopsis roots, GABA are known to initiate nitrate absorption and N metabolism. Due to reduced root absorption and impaired xylem nutrient transfer, water stress is likely to blame for a drop in P and K content (Ge *et al.*, 2012). P is anticipated to change from its immobile to insoluble form during drought stress, and P-uptake proteins (PHT1) are seen to be decreasing (Bista *et al.*, 2018).

Since calcium is an immobile element, it needs an adequate supply of water to be absorbed to its full potential (Ge *et al.*, 2012). It is well established that applying GABA to barley plants under NaCl stress increases the amount of Ca²⁺ in the plant (Ma *et al.*, 2019). Increased uptake of calcium through roots and changed calcium content in tissues led to the rise in calcium concentration. The results of this study show that sweet potato plants under drought stress that were treated with GABA at concentrations of 0.5 and 1 mM L⁻¹ had higher calcium content in their leaves. In the current study, treating sweet potato plants with GABA increases their absorption of all nutrients, which is correlated with an increase in their relative water content (LRWC). The two main micronutrients carried by the xylem stream are Fe and Zn. Application of GABA thereby enhances the uptake of nutrients in the water-stressed sweet potato leaves collectively. Reduced MDA level and improved lipid peroxidation are followed by an increase in the activity antioxidant enzymes. Drought stress was found to reduce pod production, TSS and total protein content in the current study. Water stress had an active mitigating effect on the yield attributes when GABA was applied at 1 mM L⁻¹. The enhancements in yield traits remarked in our research following 1 mM L⁻¹ GABA dose are reliable with former works in other plants. For example, El-Yazied *et al.* (2022) reported that GABA foliar usage enhanced tuber yield and mitigates drought stress in potato, indicating enhances in dry matter and antioxidant activity. Likewise, Ashraf *et al.*, (2024) observed that GABA application enhanced grains yield, chlorophyll level, and antioxidant activity in wheat under drought stress. These results support our present study, where GABA substantially enhanced

total yield, and profitable yield, also enhanced physiological attributes like RWC, and osmolyte accumulation, also enhanced nutrient uptake. Furthermore, Xu *et al.* (2021) and Hasan *et al.* (2021) highlighted the role of GABA in modulating sugar metabolism plus proline in drought stress, which promotes indirectly to yield maintenance. Together, these studies corroborate our conclusion that exogenous application of GABA at 1 mM is an effective strategy to enhance sweet potato productivity under semi-arid drought conditions. The detected enhancement in yield with 1 mM L⁻¹ GABA in drought stress is strictly linked to various physiological and biochemical alterations. GABA improved RWC, osmolyte accumulation such as proline, sugars, and FAA, plus antioxidant activity (remarkably POX), in contrast lowering MDA, it additionally increased the uptake of essential nutrients. These collective effects established crop resilience, resulting in great growth and better yield under drought stress with the application of GABA. Limitations of the research, this study was managed at a single experimental place for 2 following growing seasons. For that reason, further multi-location and multi-season studies are suggested to expand the applicability of the results.

Conclusions

The present results reveal the role of GABA as an active stress-priming neurotransmitter that enhance yield traits plus osmotic tolerance in sweet potato under drought stress. Among the examined treatments, foliar application of 1 mM GABA was the most operative concentration, reliably improving plant growth and productivity under water deficit conditions. This highpoint its agronomical importance as a practical approach for crop enhancement under drought stress.

Future investigations are necessary to elucidate the mechanistic role of GABA in the regulation of various other biomolecules during water stress. Investigations on leaf area index, stomatal conductivity and root architecture regulation by GABA are likely to provide promising agronomic benefits in near future. Furthermore, GABA application to roots and foliage are expected to provide stress-priming responses during drought stress in crops raised under deficit irrigation. Reconstruction of bio-engineered plants for GABA metabolic pathway shall serve as a better approach toward crop sustainability in arid zones. Further investigations are necessary to decipher the molecular mechanisms of GABA signalling in drought-stressed sweet potatoes plants which are likely to be associated with gene expression, regulation of transcription factors and hormonal metabolism. Moreover, more research must focus on confirmative the efficiency of 1 mM GABA under diverse environments and seasons. These guidelines figure directly on our marks and will support the basis for participating GABA into sustainable practices of sweet potato production.

Authors' Contributions

Conceptualization: MA, MEL, HG, MAA; Data curation: MA, MEL, HG, KhA, RE; Formal analysis: MA, MEL, HG, MAA; Funding acquisition: MMA; Investigation: MA, MEL, HG, MAA; Methodology: MEL, HG, MAA.; Project administration: HG, MAA.; Resources: MA, MEL, HG, MAA; Software: HG, MAA, KhA; Supervision: MA, MEL; Validation: MA, MEL; Visualization: HG, MAA; Roles/Writing - original draft: MA, MEL, HG, MMA., KhA, RE, MAA; and Writing - review & editing: MA, MEL, HG, MMA., RE, MAA

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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