

Physiological and Phytochemical Responses of Globe Amaranth (*Gomphrena globosa* L.) to Environmental Stress

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ABSTRACT: Globe amaranth (*Gomphrena globosa* L.) is an ornamental plant with potential as a source of bioactive compounds, including phenolics, flavonoids, antioxidants, and vitamin C. Drought and salinity stress are environmental factors that can affect the physiological performance and phytochemical accumulation of plants. This study aimed to evaluate the effects of drought and salinity stress on the physiological parameters and phytochemical contents of globe amaranth from the Sanur and Sibang accessions and to determine the correlation between changes in physiological parameters and phytochemical contents under stress conditions. The experiment was arranged in a factorial Completely Randomized Design (CRD) consisting of two factors, namely accession (Sanur and Sibang) and twelve stress treatments (L₀–L₁₁). The observed parameters included leaf chlorophyll content, plant height, number of leaves, root length, fresh and oven-dry weights of roots, stems, leaves, and flowers, leaf relative water content, total phenolic content, flavonoid content, antioxidant activity, and vitamin C content. Data were analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at the 5% significance level and Pearson correlation analysis. The results showed that stress treatments had a highly significant effect on all observed parameters, while accession had significant to highly significant effects on several parameters. A highly significant interaction between accession and stress treatment was also observed for all measured variables. Increasing stress levels generally reduced chlorophyll content, vegetative growth, plant biomass, and leaf relative water content, whereas phytochemical contents changed as part of the plant's adaptive response to stress. Correlation analysis revealed that phenolic content was strongly negatively correlated with most physiological parameters, whereas flavonoid content, antioxidant activity, and vitamin C exhibited variable relationships with physiological traits. These findings indicate that physiological responses and phytochemical accumulation are closely associated with the adaptive mechanisms of globe amaranth under drought and salinity stress.

KEYWORDS: *Gomphrena globosa* L., drought stress, salinity stress, physiological responses, phytochemicals, correlation.

INTRODUCTION

Globe amaranth (*Gomphrena globosa* L.) is an ornamental plant belonging to the family Amaranthaceae, known for its high adaptability to diverse environmental conditions. This plant is widely utilized not only as an ornamental and cut flower but also has potential applications as herbal tea, natural dye, and a species for land rehabilitation in marginal areas. In addition, *Gomphrena globosa* contains various bioactive compounds such as flavonoids, alkaloids, tannins, saponins, terpenoids, and betacyanins, which contribute to its pharmacological properties. Previous studies have reported that this species possesses high levels of phenolic and flavonoid compounds and exhibits significant antioxidant and antimicrobial activities (Tang et al., 2022). Furthermore, plant extracts have demonstrated biological activities including antidiabetic, antioxidant, and antiglycation effects, indicating their potential for development as natural medicinal resources (Sherif, 2021). The presence of betacyanin pigments, particularly gomphrenin, also plays an important role as a natural antioxidant with potential applications in functional food products (Drobnicka et al., 2020).

As an adaptive species, *Gomphrena globosa* has several agronomic advantages, including low input requirements, a relatively short life cycle, and tolerance to extreme environmental conditions such as drought and high temperatures. The plant is capable of growing in nutrient-poor soils and suboptimal environments, making it suitable for cultivation on marginal lands (Kumar et al., 2023; Kugler et al., 2007). In addition, it is relatively resistant to pests and diseases and can be easily propagated by seeds, supporting its potential in sustainable agricultural systems. In Bali, this plant is known as "bunga ratna" and plays an

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important role in religious rituals, where it is used as part of ceremonial offerings. Therefore, maintaining its production sustainability is crucial for supporting the socio-economic aspects of local communities (Putra et al., 2025; Suardana et al., 2020).

One of the important compounds found in plants is vitamin C (ascorbic acid), which functions as a non-enzymatic antioxidant in scavenging free radicals and reducing oxidative stress. Vitamin C also plays a role in various physiological processes, including collagen synthesis, carnitine metabolism, iron absorption, and catecholamine biosynthesis (Carr & Maggini, 2017). In plants, vitamin C is not only a nutritional component but also plays a critical role in defense mechanisms against environmental stress by detoxifying reactive oxygen species (ROS) and maintaining cellular stability (Foyer & Noctor, 2020; Smirnoff, 2018).

Abiotic stresses such as drought and salinity are major environmental factors affecting plant growth and metabolism. Drought stress leads to reduced plant water status, stomatal closure, and decreased photosynthetic rate due to limited CO₂ diffusion into leaves (Osakabe et al., 2014; Gupta et al., 2020). Meanwhile, salinity stress causes not only osmotic stress but also ionic imbalance and increased production of reactive oxygen species (ROS), which can damage cellular structures and disrupt metabolic functions (Zhu, 2016; Hasanuzzaman et al., 2020). Under such conditions, plants enhance the production of antioxidant compounds, including vitamin C, as an adaptive mechanism to neutralize ROS and reduce oxidative damage (Foyer & Noctor, 2020; Gill & Tuteja, 2010).

Previous research by Rindang Dwiyani et al. (2023) reported differences in vitamin C content between Sanur and Sibang accessions of *Gomphrena globosa*, where the Sanur accession grown in coastal environments exhibited higher vitamin C levels than the Sibang accession. This variation is presumably influenced by environmental conditions such as salinity levels and water availability, which may trigger increased production of antioxidant compounds as a response to stress. This finding is consistent with the concept that abiotic stresses, such as salinity and drought, can enhance the accumulation of antioxidant compounds, including ascorbic acid, as part of plant adaptation mechanisms to oxidative stress (Foyer & Noctor, 2020; Hasanuzzaman et al., 2020).

However, previous studies were primarily observational under natural environmental conditions, which limits the ability to specifically explain the effects of different types of environmental stress on vitamin C content in each accession. Moreover, it remains unclear how these accessions respond under controlled stress conditions, particularly drought and salinity at specific intensity levels. Plant responses to abiotic stress are strongly influenced by the type, intensity, and duration of stress, which ultimately affect physiological mechanisms and the accumulation of bioactive compounds (Osakabe et al., 2014).

Therefore, there is still a research gap in understanding the relationship between types and levels of environmental stress and the physiological responses as well as phytochemical changes in *Gomphrena globosa*. This study was conducted by applying drought stress at 40% and 60% of field capacity and salinity stress at several concentration levels (0.2, 0.4, and 0.6 ppm), including their combinations, to Sanur and Sibang accessions with similar purple flower characteristics. This approach aims to analyze physiological responses and phytochemical content, particularly vitamin C, in order to understand plant adaptation mechanisms under environmental stress and to evaluate whether differences between accessions remain consistent under controlled stress conditions.

RESEARCH METHOD

Research Design

This study employed an experimental method using a completely randomized design (CRD) to analyze the physiological and phytochemical responses of globe amaranth (*Gomphrena globosa* L.) under environmental stress conditions. The treatments consisted of different levels of environmental stress, such as drought stress, salinity stress, and/or temperature stress, depending on the experimental setup. Each treatment was replicated several times to ensure data reliability.

Physiological parameters and phytochemical contents were measured to evaluate plant responses. Data were analyzed using statistical methods to determine the significance of treatment effects.

Research Location and Time

The experiment was conducted in a greenhouse and laboratory of the Agroecotechnology Study Program, Faculty of Agriculture, Udayana University, Denpasar, Bali, Indonesia. Laboratory analyses were carried out in relevant agricultural and biological laboratories.

The research was conducted from August 2025 to January 2026, covering plant cultivation, treatment application, observation, laboratory analysis, and data processing.

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Tools and Materials

The tools used in this study included planting pots, analytical balance, spectrophotometer, oven, pH meter, measuring cylinder, pipettes, and laboratory glassware. Supporting tools included a laptop with Microsoft Office and statistical software (e.g., SPSS or R).

The materials used consisted of globe amaranth (*Gomphrena globosa* L.) seeds, planting media (soil, compost, sand), distilled water, and chemical reagents for phytochemical analysis such as ethanol, methanol, and other specific reagents depending on the parameters measured.

RESEARCH IMPLEMENTATION

The research was conducted through the following stages:

1. Preparation Stage

A literature review was conducted on plant physiological responses, phytochemical compounds, and environmental stress factors. Materials and equipment were prepared prior to the experiment.

2. Plant Cultivation

Seeds of *Gomphrena globosa* L. were planted in prepared media and maintained under controlled conditions until they reached a certain growth stage before treatment application.

3. Treatment Application

Environmental stress treatments were applied according to the experimental design, such as:

- a. Drought stress (different watering intervals or field capacity levels)
- b. Salinity stress (NaCl concentration levels)
- c. Temperature stress (if applicable)

4. Observation and Measurement

Observations were conducted on physiological and phytochemical parameters, including:

- a. Physiological parameters (plant height, leaf number, chlorophyll content, relative water content)
- b. Phytochemical content (total phenolics, flavonoids, antioxidant activity, etc.)

5. Laboratory Analysis

Plant samples were collected and analyzed using standard laboratory methods to determine phytochemical content and physiological indicators.

6. Data Collection

All experimental data were recorded systematically during the observation period and laboratory analysis.

Observation Variables

The variables observed in this study included:

1. Plant height (cm)
2. Number of leaves
3. Chlorophyll content
4. Relative water content
5. Total phenolic content
6. Flavonoid content
7. Antioxidant activity
8. Other stress-related physiological indicators

Data Analysis

Data were analyzed using analysis of variance (ANOVA) to determine the effect of treatments. If significant differences were found, further tests such as Duncan's Multiple Range Test (DMRT) or Least Significant Difference (LSD) were conducted.

The results were presented in the form of tables, graphs, and descriptive analysis to explain the physiological and phytochemical responses of *Gomphrena globosa* L. under environmental stress conditions.

RESULTS

Significance of Treatment Effects on Observed Variables

Based on the results of the analysis of variance, the accession factor (A) had a highly significant effect ($P < 0.01$) on leaf number and root length, and a significant effect ($P < 0.05$) on leaf chlorophyll content, fresh stem weight, fresh leaf weight, fresh flower weight, oven-dry stem weight, oven-dry leaf weight, total phenolic content, and vitamin C content. Meanwhile, the

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accession factor had no significant effect ($P>0.05$) on plant height, fresh root weight, oven-dry root weight, oven-dry flower weight, leaf relative water content (RWC), flavonoid content, and antioxidant content.

The stress treatment factor (L) and the interaction between accession and stress treatment ($A \times L$) had a highly significant effect ($P<0.01$) on all observed variables. This indicates that the response of each accession to the stress treatment differed for each observed variable.

Table 1 Significance of Ratna Flower Accession (A) and Stress (L) on Observed Variables

No.	Variable	Treatment		Interaction
		A	L	
1	Leaf chlorophyll content (SPAD)	*	**	**
2	Plant height (cm)	Ns	**	**
3	Leaf number (strands)	**	**	**
4	Fresh root weight (g)	Ns	**	**
5	Fresh stem weight (g)	*	**	**
6	Fresh leaf weight (g)	*	**	**
7	Fresh flower weight (g)	*	**	**
8	Root length (cm)	**	**	**
9	Oven-dry root weight (g)	Ns	**	**
10	Oven-dry stem weight (g)	*	**	**
11	Oven-dry leaf weight (g)	*	**	**
12	Oven-dry flower weight (g)	Ns	**	**
13	Leaf relative water content (RWC) (%)	Ns	**	**
14	Total phenolic content (mg GAE/g)	*	**	**
15	Flavonoid content (mg QE/g)	Ns	**	**
16	Antioxidant content (mg AEAC/g)	Ns	**	**
17	Vitamin C content (mg/g)	*	**	**

Note: * = Significant Effect ($P>0.05$); ** = Highly Significant Effect ($P<0.01$); ns = Not Significant ($P\leq 0.05$).

Effect of Stress on Physiological Characteristics of Ratna Flower Accessions

Leaf Chlorophyll Content

The results of the further test showed that all combinations of accession and stress-level treatments carried the same letter notation, so there was no significant difference in leaf chlorophyll content. Nevertheless, descriptively the leaf chlorophyll content varied among treatment combinations. In accession A1, leaf chlorophyll content ranged from 39.95–76.50 SPAD, with the highest value in treatment L3 and the lowest in treatment L9. Meanwhile, in accession A2, leaf chlorophyll content ranged from 39.90–67.15 SPAD, with the highest value in treatment L0 and the lowest in treatment L2. Descriptively, accession A2 tended to have higher leaf chlorophyll content than A1 at several stress levels, although this difference was not significant based on the further test results (Table 2).

Leaf RWC (%)

The results of Duncan's further test at the 5% significance level showed that the combination of accession and stress-level treatments produced a significant difference in the leaf relative water content (RWC) of the ratna flower plant (Table 2). Leaf RWC values ranged from 0.83 to 1.05. The highest RWC value was obtained in the A1L11 treatment combination (1.05), which differed significantly from all other treatment combinations. The lowest RWC value was obtained in the A1L4 treatment combination (0.83), which did not differ significantly from A2L4 (0.84) and A1L8 (0.84).

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Table 2. Interaction Between Ratna Flower Accession (A) and Stress (L) on Leaf Chlorophyll (SPAD) and Leaf RWC (%)

Chlorophyll Content (SPAD)			Leaf RWC (%)	
Treatment	A ₁	A ₂	A ₁	A ₂
L ₀	42,32hi	40,35f	0,98gh	0,93def
L ₁	25,53a	20,71a	0,99ghi	0,88abc
L ₂	30,69b	28,19b	0,90cd	0,88abc
L ₃	36,87c	38,24d	0,91cde	0,91de
L ₄	39,03d	36,16c	0,83a	0,84a
L ₅	42,82ij	42,56hij	0,92cdef	0,90bcd
L ₆	43,76k	43,21k	0,89bc	0,90bcd
L ₇	46,37l	45,74l	0,94cdefg	0,96defg
L ₈	39,40de	42,37hi	0,84ab	0,85ab
L ₉	40,48g	41,69g	0,91cde	0,93def
L ₁₀	39,53def	42,03gh	0,94cdefg	0,93def
L ₁₁	41,97h	38,87e	1,05j	0,98fg

Note: Mean values followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level ($\alpha = 0.05$).

Plant Height (cm)

The results of Duncan's further test at the 5% significance level showed that the combination of accession and stress-level treatments produced a significant difference in plant height. In accession A₁, plant height ranged from 31.77–39.67 cm, with the highest value obtained in treatment L₀ (39.67 cm) and the lowest in treatment L₄ (31.77 cm). Meanwhile, in accession A₂, plant height ranged from 31.87–38.77 cm, with the highest value in treatment L₀ (38.77 cm) and the lowest in treatments L₁ and L₄ (31.87 cm). In general, stress treatment caused a decrease in plant height compared with the control (L₀), although the magnitude of the decrease differed between accessions (Table 2).

Leaf Number (Strands)

The results of the combination treatment between accession and stress level produced a significant difference in leaf number. In accession A₁, leaf number ranged from 36.00–63.33 strands, with the highest leaf number in treatment L₀ (63.33 strands) and the lowest in treatment L₃ (36.00 strands). In accession A₂, leaf number ranged from 27.67–72.33 strands, with the highest value in treatment L₀ (72.33 strands) and the lowest in treatment L₂ (27.67 strands). In general, stress treatment reduced leaf number compared with the control, with different responses between accessions (Table 2).

Table 3. Interaction Between Ratna Flower Accession (A) and Stress (L) on Plant Height (cm), Leaf Number (Strands), and Root Length (cm)

Plant Height (cm)			Leaf Number (Strands)		Root Length (cm)	
Treatment	A ₁	A ₂	A ₁	A ₂	A ₁	A ₂
L ₀	39,67d	38,77d	63,33k	72,33ijk	35,80g	24,80a
L ₁	32,00ab	31,87a	39,67ab	31,00ab	38,77l	35,77j
L ₂	32,10ab	32,33abc	42,00bc	27,67a	26,20c	30,23f
L ₃	35,93c	35,90cd	36,00a	62,67fg	35,87gh	33,27i
L ₄	31,77a	31,87ab	53,00gh	58,67def	23,57ab	29,60de
L ₅	36,90c	36,43d	47,00cde	56,00cd	36,77j	32,13gh
L ₆	35,60b	36,00d	47,00cdef	63,67fgh	26,60cd	32,00g
L ₇	37,80c	37,90d	51,00defg	50,67c	37,50k	29,77e
L ₈	37,03c	36,90d	45,67cd	67,67hi	28,70e	29,20d
L ₉	37,57c	36,90d	56,33ghi	69,67ij	34,80f	27,20b
L ₁₀	37,07c	36,70d	57,67hij	62,67fg	36,00ghi	27,27c
L ₁₁	35,70c	36,23d	62,67jk	56,00cde	23,20a	38,00k

Note: Mean values followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level ($\alpha = 0.05$).

Root Length (cm)

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The results of the further test showed that the interaction between accession and stress-level treatments produced a significant difference in root length. In accession A1, root length ranged from 23.20–38.77 cm, with the highest value in treatment L1 (38.77 cm) and the lowest in treatment L11 (23.20 cm). In accession A2, root length ranged from 24.80–38.00 cm, with the highest value in treatment L11 (38.00 cm) and the lowest in treatment L0 (24.80 cm). This difference in response indicates that the effect of stress on root growth is influenced by the characteristics of each accession (Table 3).

Fresh Leaf Weight (g)

The results of Duncan's test (0.05) showed that the combination of accession and stress-level treatments produced a significant difference in fresh leaf weight. In accession A1, fresh leaf weight ranged from 8.45–22.40 g, with the highest value obtained in treatment L8 (22.40 g) and the lowest in treatment L1 (8.45 g). In accession A2, fresh leaf weight ranged from 7.75–22.15 g, with the highest value in treatment L0 (22.15 g) and the lowest in treatment L1 (7.75 g) (Table 4). Descriptively, fresh leaf weight in both accessions tended to be higher in treatments L0 and L8 compared with the other treatments.

Fresh Flower Weight (g)

Based on Duncan's further test (0.05), the combination of accession and stress-level treatments produced a significant difference in fresh flower weight. In accession A1, fresh flower weight ranged from 0.17–3.19 g, with the highest value obtained in treatment L6 (3.19 g) and the lowest in treatment L4 (0.17 g). Meanwhile, in accession A2, fresh flower weight ranged from 0.17–3.23 g, with the highest value in treatment L6 (3.23 g) and the lowest in treatment L3 (0.17 g). In general, both accessions showed nearly similar responses, with treatment L6 producing the highest fresh flower weight (Table 4).

Fresh Stem Weight (g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in fresh stem weight. In accession A1, fresh stem weight ranged from 4.58–30.81 g, with the highest value obtained in treatment L0 (30.81 g) and the lowest in treatment L1 (4.58 g). Meanwhile, in accession A2, fresh stem weight ranged from 4.52–30.56 g, with the highest value in treatment L0 (30.56 g) and the lowest in treatment L1 (4.52 g) (Table 4). These results indicate that the control treatment produced the highest fresh stem weight in both accessions.

Fresh Root Weight (g)

Based on the further test, the combination of accession and stress-level treatments produced a significant difference in fresh root weight. In accession A1, fresh root weight ranged from 2.56–17.66 g, with the highest value obtained in treatment L0 (17.66 g) and the lowest in treatment L4 (2.56 g). In accession A2, fresh root weight ranged from 2.63–13.33 g, with the highest value in treatment L1 (13.33 g) and the lowest in treatment L2 (2.63 g) (Table 4). Descriptively, the fresh root weight response differed between the two accessions, indicating that the effect of stress on root growth is influenced by the characteristics of each accession.

Table 4. Effect of Stress (L) on Ratna Flower Accession (A) on Fresh Flower Weight (g), Fresh Leaf Weight (g), Fresh Stem Weight (g), and Fresh Root Weight (g)

Treatment	Fresh Flower Weight (g)		Fresh Leaf Weight (g)		Fresh Stem Weight (g)		Fresh Root Weight (g)	
	A1	A2	A1	A2	A1	A2	A1	A2
L ₀	1,48j	1,49i	21,01i	22,15kl	30,81l	30,56l	17,66l	3,99ab
L ₁	0,71bc	0,24abc	8,45a	7,75a	4,58a	4,52a	6,37abcdehgh	13,33l
L ₂	1,17gh	0,67de	11,76b	10,33b	8,18b	8,11b	8,29abcdehghij	2,63a
L ₃	0,94cdef	0,17a	21,51j	19,66i	20,85k	16,43ef	5,88abcdeh	3,83abcde
L ₄	0,17a	0,19ab	13,45d	12,80d	16,36e	16,29e	2,56a	5,73abcdehghij
L ₅	1,32jk	1,35ij	13,67de	13,25de	18,65gh	18,73i	7,78abcdehghi	3,15ab
L ₆	3,19jkl	3,23k	14,59f	15,93g	12,15c	12,09c	4,98abc	4,14abcdeh
L ₇	1,05efg	1,11g	12,45c	11,31c	12,40d	12,26d	9,09cdehghijk	3,63abcd
L ₈	0,82cde	0,81ef	22,40jk	21,79k	19,39i	19,34j	5,53abcd	4,70abcdehgh
L ₉	0,80cd	0,81ef	21,79j	20,10ij	18,63g	18,56h	6,16abcdehfg	4,19abcdehfg
L ₁₀	0,52b	0,52d	17,42h	17,16h	20,25j	20,20k	5,65abcde	5,34abcdehghijk
L ₁₁	1,23ghi	1,20h	15,03fg	14,05f	18,33f	18,27g	3,99ab	3,73abc

Note: Mean values followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level ($\alpha = 0.05$).

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Oven-Dry Leaf Weight (g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in oven-dry leaf weight (ODW). In accession A1, leaf ODW ranged from 2.10–5.59 g, with the highest value obtained in treatment L8 (5.59 g) and the lowest in treatment L1 (2.10 g). In accession A2, leaf ODW ranged from 1.92–5.53 g, with the highest value in treatment L0 (5.53 g) and the lowest in treatment L1 (1.92 g). Descriptively, treatments L0 and L8 produced relatively higher leaf ODW values than the other treatments.

Oven-Dry Flower Weight (g)

Based on the results of the further test, the interaction between accession and stress-level treatments produced a significant difference in oven-dry flower weight (ODW). In accession A1, flower ODW ranged from 0.13–0.53 g, with the highest value obtained in treatment L8 (0.53 g) and the lowest in treatment L2 (0.13 g). Meanwhile, in accession A2, flower ODW ranged from 0.13–0.46 g, with the highest value in treatments L3 and L5 (0.46 g) and the lowest in treatment L10 (0.13 g). Descriptively, flower ODW values in both accessions tended to increase under several stress treatments compared with the others.

Oven-Dry Stem Weight (g)

The results of the further test on the interaction between accession and stress-level treatments produced a significant difference in oven-dry stem weight (ODW). In accession A1, stem ODW ranged from 1.19–4.69 g, with the highest value obtained in treatment L8 (4.69 g) and the lowest in treatment L1 (1.19 g). Meanwhile, in accession A2, stem ODW ranged from 1.09–4.45 g, with the highest value in treatment L8 (4.45 g) and the lowest in treatment L1 (1.09 g). These results indicate that both accessions had a relatively similar response pattern to stress treatment.

Oven-Dry Root Weight (g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in oven-dry root weight (ODW). In accession A1, root ODW ranged from 1.19–2.23 g, with the highest value obtained in treatment L0 (2.23 g) and the lowest in treatment L8 (1.19 g). Meanwhile, in accession A2, root ODW ranged from 0.76–2.97 g, with the highest value in treatment L0 (2.97 g) and the lowest in treatment L4 (0.76 g). Descriptively, the control treatment (L0) produced the highest root ODW value in both accessions, whereas certain stress treatments caused a decrease in root dry weight.

Table 5. Effect of Stress (L) on Ratna Flower Accession (A) on Oven-Dry Flower Weight (g), Oven-Dry Leaf Weight (g), Oven-Dry Stem Weight (g), and Oven-Dry Root Weight (g)

Treatment	Oven-Dry Flower Weight (g)		Oven-Dry Leaf Weight (g)		Oven-Dry Stem Weight (g)		Oven-Dry Root Weight (g)	
	A1	A2	A1	A2	A1	A2	A1	A2
L ₀	0,32cde	0,33bc	5,25i	5,53j	3,87g	4,06jk	2,23l	2,97l
L ₁	0,22bc	0,25b	2,10a	1,92a	1,19a	1,09a	1,23ab	1,67fghi
L ₂	0,13a	0,14a	2,89b	2,59b	2,03b	1,81b	1,68efghij	1,53def
L ₃	0,46gh	0,46def	5,37ij	4,90h	4,34j	3,96j	1,59defg	1,78ghij
L ₄	0,38def	0,45cde	3,31e	3,20d	3,07e	2,95efg	1,52def	0,76a
L ₅	0,47ghi	0,46def	3,36ef	3,31e	2,90d	2,85e	1,70fghijk	1,84ghijk
L ₆	0,44fg	0,41cd	2,98bc	2,97c	2,56d	2,54d	1,39abcd	1,13b
L ₇	0,20abc	0,15a	3,12d	2,82c	2,19c	2,00c	1,30abc	1,62fg
L ₈	0,53ghij	0,43cde	5,59l	5,44j	4,69k	4,45k	1,19a	1,34bcd
L ₉	0,33def	0,21ab	5,45jk	5,00hi	3,90i	3,57i	1,65efgh	1,40cde
L ₁₀	0,17ab	0,13a	4,32h	4,27g	3,49gh	3,42h	1,65efghi	1,69fgh
L ₁₁	0,30cd	0,21ab	3,74g	3,51f	3,11ef	2,93ef	1,46cde	1,24bc

Note: Mean values followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level ($\alpha = 0.05$).

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Effect of Stress on the Phytochemical Content of Ratna Flower Accessions

Total Phenolic Content (mg GAE/g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in total phenolic content. In accession A1, total phenolic content ranged from 53.10–192.20 mg GAE/g, with the highest value obtained in treatment L2 (192.20 mg GAE/g) and the lowest in treatment L11 (53.10 mg GAE/g). In accession A2, total phenolic content ranged from 51.70–187.65 mg GAE/g, with the highest value in treatment L2 (187.65 mg GAE/g) and the lowest in treatment L11 (51.70 mg GAE/g) (Table 6). Descriptively, both accessions showed a relatively similar response pattern, in which treatment L2 produced the highest total phenolic content, while treatment L11 produced the lowest.

Flavonoid Content (mg GAE/g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in flavonoid content. In accession A1, flavonoid content ranged from 15.70–62.33, with the highest value obtained in treatment L5 (62.33) and the lowest in treatment L8 (15.70) (Table 6). Meanwhile, in accession A2, flavonoid content ranged from 20.17–60.53, with the highest value in treatment L6 (60.53) and the lowest in treatment L5 (20.17). These results indicate that the response of flavonoid content to stress treatment differed between accessions.

Antioxidant Content (mg AEAC/g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in antioxidant content. In accession A1, antioxidant content ranged from 23.20–38.77, with the highest value obtained in treatment L1 (38.77) and the lowest in treatment L11 (23.20) (Table 6). Meanwhile, in accession A2, antioxidant content ranged from 24.80–38.00, with the highest value in treatment L11 (38.00) and the lowest in treatment L0 (24.80). Descriptively, both accessions showed different responses to stress treatment in producing antioxidant activity.

Vitamin C Content (mg/g)

The results of the further test showed that the combination of accession and stress-level treatments produced a significant difference in vitamin C content. In accession A1, vitamin C content ranged from 44.99–69.66, with the highest value obtained in treatment L1 (69.66) and the lowest in treatment L8 (44.99). In accession A2, vitamin C content ranged from 43.70–68.30, with the highest value in treatment L1 (68.30) and the lowest in treatment L8 (43.70) (Table 6). Descriptively, both accessions showed a relatively similar response pattern, with the highest vitamin C content obtained in treatment L1 and the lowest in treatment L8.

Table 6. Effect of Stress (L) on Ratna Flower Accession (A) on Antioxidant Content (mg AEAC/g), Vitamin C Content (mg/g), Flavonoid Content (mg GAE/g), and Total Phenolic Content (mg GAE/g)

Antioxidant AEAC/g)	Content (mg		Vitamin C Content (mg/g)		Flavonoid Content (mg GAE/g)		Total Phenolic Content (mg GAE/g)	
Treatment	A1	A2	A1	A2	A1	A2	A1	A2
L ₀	35,80g	24,80a	64,62k	63,55k	47,97k	22,97c	72,57d	71,24d
L ₁	38,77l	35,77j	69,66kl	68,30l	38,80j	46,53k	164,06k	159,70k
L ₂	26,20c	30,23f	57,24i	55,90i	26,20f	37,90j	192,20l	187,65l
L ₃	35,87gh	33,27i	49,12e	48,00e	26,80g	25,60f	98,15i	96,62i
L ₄	23,57ab	29,60de	47,31b	46,10c	20,90b	26,00fg	94,21h	92,24h
L ₅	36,77j	32,13gh	52,08g	50,90g	62,33l	20,17a	84,29f	82,42f
L ₆	26,60cd	32,00g	49,02d	47,90d	23,87d	60,53l	76,03e	73,82e
L ₇	37,50k	29,77e	57,56j	56,10j	27,60h	23,07d	91,16g	89,10g
L ₈	28,70e	29,20d	44,99a	43,70a	15,70a	26,50gh	62,14b	60,92b
L ₉	34,80f	27,20b	54,01h	52,70h	24,90e	20,93b	68,08c	66,82c
L ₁₀	36,00ghi	27,27c	51,66f	50,60f	35,03i	23,97e	106,25j	104,08j
L ₁₁	23,20a	38,00k	47,32bc	45,95b	22,97c	33,97i	53,10a	51,70a

Note: Mean values followed by the same letter indicate no significant difference based on Duncan's Multiple Range Test (DMRT) at the 5% significance level ($\alpha = 0.05$).

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Correlation between Changes in Physiological Parameters and Phytochemical Content in Ratna Flower

Antioxidant Content (mg AEAC/g)

Antioxidant content had a positive relationship with most physiological parameters. A strong positive correlation was obtained with flower ODW ($r = 0.68$), while moderate positive correlations were shown with chlorophyll content ($r = 0.55$), fresh stem weight ($r = 0.52$), stem ODW ($r = 0.46$), leaf number ($r = 0.42$), fresh leaf weight ($r = 0.39$), fresh flower weight ($r = 0.34$), leaf ODW ($r = 0.32$), and plant height ($r = 0.28$). Meanwhile, the relationships with root length ($r = -0.15$), fresh root weight ($r = 0.15$), root ODW ($r = 0.09$), and leaf RWC ($r = -0.05$) were classified as weak to very weak (Table 7). These results indicate that an increase in antioxidant activity tends to be associated with increased plant biomass, particularly flower biomass.

Vitamin C Content (mg/g)

Vitamin C content showed varied relationships with the physiological parameters. Moderate positive correlations were obtained with fresh root weight ($r = 0.50$), root ODW ($r = 0.47$), root length ($r = 0.32$), and leaf RWC ($r = 0.32$) (Table 7). Conversely, moderate negative correlations were shown with stem ODW ($r = -0.52$), chlorophyll content ($r = -0.51$), and flower ODW ($r = -0.46$). The relationships with plant height ($r = -0.09$), leaf number ($r = -0.30$), fresh flower weight ($r = -0.07$), fresh leaf weight ($r = -0.35$), leaf ODW ($r = -0.30$), and fresh stem weight ($r = -0.20$) were classified as weak to moderate. Overall, vitamin C content had a closer relationship with root system characteristics than with canopy growth parameters.

Flavonoid Content (mg GAE/g)

Flavonoid content generally showed weak to moderate relationships with the physiological parameters. Moderate positive correlations were found with root ODW ($r = 0.59$) and fresh root weight ($r = 0.44$), while weak positive correlations were found with root length ($r = 0.33$), fresh stem weight ($r = 0.26$), plant height ($r = 0.24$), and leaf RWC ($r = 0.25$) (Table 7). The relationships with chlorophyll content ($r = 0.00$), leaf number ($r = 0.01$), fresh flower weight ($r = 0.08$), flower ODW ($r = 0.06$), fresh leaf weight ($r = -0.12$), leaf ODW ($r = -0.09$), and stem ODW ($r = -0.13$) were classified as very weak. In general, flavonoid content did not show a strong relationship with plant growth.

Table 7. Correlation Coefficients between Physiological Parameters and Phytochemical Content in Ratna Flower (*Gomphrena globosa* L.) under Drought and Salinity Stress

Physiological Parameter	Phenolic (mg GAE/g)	Flavonoid (mg GAE/g)	Antioxidant AEAC/g)	(mg Vitamin C (mg/g)
Chlorophyll content	-0,80	0,00	0,55	-0,51
Plant height	-0,70	0,24	0,28	-0,09
Leaf number	-0,71	0,01	0,42	-0,30
Root length	0,12	0,33	-0,15	0,32
Fresh root weight	-0,11	0,44	0,15	0,50
Root ODW	-0,01	0,59	0,09	0,47
Fresh flower weight	-0,29	0,08	0,34	-0,07
Flower ODW	-0,49	0,06	0,68	-0,46
Fresh leaf weight	-0,62	-0,12	0,39	-0,35
Leaf ODW	-0,57	-0,09	0,32	-0,30
Fresh stem weight	-0,67	0,26	0,52	-0,20
Stem ODW	-0,66	-0,13	0,46	-0,52
Leaf RWC	-0,14	0,25	-0,05	0,32

Total Phenolic Content (mg GAE/g)

The results of the correlation analysis showed that total phenolic content had a negative relationship with most of the plant's physiological parameters. A very strong negative correlation was shown with chlorophyll content ($r = -0.80$), while strong negative correlations were found with plant height ($r = -0.70$), leaf number ($r = -0.71$), fresh leaf weight ($r = -0.62$), fresh stem weight ($r = -0.67$), and oven-dry stem weight ($r = -0.66$) (Table 7). In addition, total phenolic content had a moderate negative correlation with leaf ODW ($r = -0.57$) and flower ODW ($r = -0.49$). In contrast, the correlations with root length ($r = 0.12$), fresh root weight ($r = -0.11$), root ODW ($r = -0.01$), fresh flower weight ($r = -0.29$), and leaf RWC ($r = -0.14$) were classified as weak to very weak. These results indicate that an increase in total phenolic content tends to be followed by a decrease in the plant's vegetative growth.

DISCUSSION

Effect of Environmental Stress on the Physiological Responses of Globe Amaranth Accessions

The results showed that drought and salinity stress treatments had a highly significant effect ($P < 0.01$) on all physiological parameters of globe amaranth (*Gomphrena globosa* L.), both as single treatment effects and through interactions with accessions. This indicates that plant physiological responses are influenced not only by the level of stress applied but also by the genetic characteristics of each accession, which determine the plant's adaptive capacity under unfavorable environmental conditions. These differences were reflected in variations in chlorophyll content, plant height, number of leaves, root length, plant biomass, and relative water content of leaves across treatment combinations. Accessions with better adaptive capacity tended to maintain their physiological activity, resulting in smaller reductions in growth compared to more stress-sensitive accessions (Mahajan & Pal, 2023). This finding highlights the important role of genetic factors in determining plant tolerance to abiotic stress.

Leaf chlorophyll content in globe amaranth (*Gomphrena globosa* L.) generally decreased under most stress treatments compared to the control (L0), although the magnitude of reduction varied among accessions. The decline in chlorophyll content represents a major physiological response to drought and salinity stress, indicating disruption of photosynthetic processes due to reduced stability of photosynthetic pigments. Drought stress limits water availability, reduces turgor pressure, and inhibits chlorophyll synthesis, whereas salinity stress induces the accumulation of Na^+ and Cl^- ions that interfere with the uptake of essential nutrients, particularly magnesium (Mg) and nitrogen (N), which are crucial for chlorophyll formation. In addition, both stress types enhance the production of reactive oxygen species (ROS), which can damage chloroplast membranes, accelerate chlorophyll degradation, and reduce photosynthetic efficiency (Hasanuzzaman et al., 2023). A reduction in chlorophyll content decreases the leaf's ability to capture light energy, thereby lowering the rate of photosynthesis and assimilate production, ultimately inhibiting plant growth and biomass accumulation. These findings are consistent with Hossain et al. (2022), who reported that drought and salinity stress, individually or in combination, reduce chlorophyll content through inhibition of chlorophyll biosynthesis, pigment degradation, chloroplast structural damage, and increased oxidative stress, leading to decreased photosynthetic efficiency and plant growth.

Plant growth, as indicated by plant height and leaf number, generally declined under most stress treatments compared to the control (L0), although the degree of reduction varied among accessions. This decrease suggests that drought and salinity stress inhibit vegetative growth processes. Stress conditions reduce soil water potential and increase osmotic pressure in the root zone, thereby limiting the plant's ability to absorb water. As a result, cell turgor pressure decreases, inhibiting cell division and elongation, which directly reduces plant height. Furthermore, plants respond to stress by closing stomata to minimize water loss through transpiration. However, stomatal closure restricts CO_2 diffusion into the leaves, thereby reducing photosynthesis and the production of assimilates required for vegetative growth. Reduced assimilate availability leads to inhibited formation of new leaves and slower plant growth compared to unstressed plants. These results are in agreement with Zandalinas et al. (2023), who stated that combined drought and salinity stress reduce plant growth through disruption of water balance, decreased stomatal conductance, reduced photosynthesis rate, and inhibition of cell division and elongation.

Root system responses showed a different pattern compared to the shoot. In some treatments, root length was maintained or even increased, while root fresh and dry weights tended to decrease. This condition indicates an adaptive mechanism in which plants enhance root elongation to reach deeper soil layers for water acquisition. However, under more severe or prolonged stress, root biomass also declines due to inhibited cell division and reduced allocation of photosynthates to the roots.

Plant biomass, as indicated by fresh and dry weights of stems, leaves, and flowers, generally decreased under most stress treatments compared to the control (L0), although responses varied among accessions. This reduction reflects impaired plant growth due to drought and salinity stress. The decrease in biomass is associated with reduced photosynthetic rates resulting from lower chlorophyll content and stomatal closure. Reduced assimilate production leads to lower dry matter accumulation in plant organs. Moreover, salinity stress causes the accumulation of toxic Na^+ and Cl^- ions, disrupting nutrient balance and cellular metabolism, while drought stress reduces soil water potential, limiting water and nutrient uptake by roots. These conditions decrease the efficiency of assimilate translocation to both vegetative and generative organs, resulting in reduced biomass accumulation. These findings are consistent with Parihar et al. (2015), who reported that drought and salinity stress inhibit plant growth through reduced photosynthetic efficiency, impaired water and nutrient uptake, and decreased biomass accumulation.

Relative water content (RWC) of leaves was also significantly affected by drought and salinity stress, as indicated by variations across treatment combinations and accessions. In general, stress treatments reduced RWC compared to the control, although some treatment combinations maintained relatively high RWC values. A decrease in RWC reflects a reduced ability of leaf tissues to maintain water status due to limited water availability in the growing medium and increased osmotic pressure caused by salt accumulation. This condition reduces water uptake by roots, leading to decreased cellular water content and turgor

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pressure. Conversely, accessions capable of maintaining higher RWC likely possess better physiological adaptation mechanisms, such as osmotic adjustment through the accumulation of osmoprotectants including proline, soluble sugars, and glycine betaine, which help maintain cellular water balance under stress. The ability to maintain RWC is an important indicator of plant tolerance to abiotic stress, as it is closely associated with the maintenance of physiological processes, particularly photosynthesis and growth. These findings are consistent with Ahmad Pessarakli and Parvaiz Ahmad (2021), who reported that stress-tolerant plants are generally able to maintain leaf RWC through osmotic adjustment mechanisms, thereby minimizing physiological damage and sustaining metabolic activity.

Effect of Environmental Stress on Phytochemical Content of Globe Amaranth Accessions

The results showed that drought and salinity stress treatments had a highly significant effect ($P < 0.01$) on all phytochemical parameters of globe amaranth (*Gomphrena globosa* L.), including total phenolic content, flavonoids, antioxidant activity, and vitamin C. In addition to the main effects, the interaction between accession and stress level also significantly influenced all parameters. This indicates that changes in secondary metabolite content are determined not only by stress intensity but also by the genetic characteristics of each accession. Differences in responses between the Sanur and Sibang accessions suggest variation in their ability to activate physiological and biochemical mechanisms as adaptive responses to stress conditions.

In general, increasing stress levels led to changes in phytochemical compound content. Total phenolic content tended to increase under certain stress treatments compared to the control. This increase is considered an adaptive response to enhanced production of reactive oxygen species (ROS) under stress conditions. Phenolic compounds act as non-enzymatic antioxidants that scavenge free radicals, thereby protecting cell membranes, proteins, and photosynthetic pigments from oxidative damage (Ray et al., 2024).

Flavonoid content also showed significant changes under stress treatments. In general, flavonoid levels increased under higher stress intensity. Flavonoids are secondary metabolites that function as natural antioxidants and play an important role in neutralizing ROS generated under stress. Their accumulation is a key adaptive mechanism that helps maintain membrane stability, protect photosynthetic pigments, and sustain cellular metabolic activity (Sharma et al., 2022).

Antioxidant activity in globe amaranth also showed significant variation due to stress treatments. The results indicated that antioxidant activity increased under certain stress levels compared to the control. This increase reflects the activation of plant defense systems to mitigate the harmful effects of ROS. High antioxidant activity plays a crucial role in maintaining cell membrane integrity, reducing oxidative damage, and preserving physiological functions under stress conditions (Wang et al., 2024).

Vitamin C content was also significantly affected by stress treatments. The results showed variations in vitamin C levels across treatment combinations and accessions, indicating metabolic responses to unfavorable environmental conditions. Ascorbic acid (vitamin C) is a non-enzymatic antioxidant that reduces ROS and maintains cellular redox balance. Increased vitamin C content under stress conditions indicates activation of biochemical defense mechanisms to minimize oxidative damage, whereas decreased levels under certain treatments may result from its extensive utilization in ROS detoxification processes (Wang et al., 2024).

Correlation Between Physiological Parameters and Phytochemical Content in Globe Amaranth

Correlation analysis was conducted to determine the relationship between physiological parameters and phytochemical content in globe amaranth (*Gomphrena globosa* L.) under drought and salinity stress. The results showed that each phytochemical parameter exhibited different degrees of correlation with physiological parameters, indicating that physiological changes under stress are associated with variations in secondary metabolite accumulation as part of plant adaptation mechanisms.

Phenolic content showed a very strong negative correlation with chlorophyll content ($r = -0.80$), plant height ($r = -0.70$), and leaf number ($r = -0.71$). It also showed strong negative correlations with leaf fresh weight ($r = -0.62$), stem fresh weight ($r = -0.67$), stem dry weight ($r = -0.66$), and leaf dry weight ($r = -0.57$). In contrast, its relationship with root length ($r = 0.12$), root fresh weight ($r = -0.11$), root dry weight ($r = -0.01$), and leaf RWC ($r = -0.14$) was very weak. These results indicate that phenolic accumulation tends to increase when vegetative growth and photosynthetic capacity decline under stress conditions, representing an adaptive response to oxidative stress (Nakabayashi et al., 2014).

Flavonoid content showed relatively weak relationships with most physiological parameters. Moderate positive correlations were observed with root dry weight ($r = 0.59$) and root fresh weight ($r = 0.44$), while weak positive correlations were found with root length ($r = 0.33$), plant height ($r = 0.24$), stem fresh weight ($r = 0.26$), and leaf RWC ($r = 0.25$). Flavonoids showed almost no correlation with chlorophyll content ($r = 0.00$), leaf number ($r = 0.01$), flower fresh weight ($r = 0.08$), or flower dry weight ($r = 0.06$). This suggests that flavonoid accumulation is more closely associated with root physiological responses than shoot growth. Flavonoids function as natural antioxidants that help maintain membrane stability and reduce oxidative stress effects (Agati et al., 2012).

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Antioxidant activity showed strong positive correlations with flower dry weight ($r = 0.68$), chlorophyll content ($r = 0.55$), and stem fresh weight ($r = 0.52$). Moderate positive correlations were observed with leaf number ($r = 0.42$), leaf fresh weight ($r = 0.39$), flower fresh weight ($r = 0.34$), leaf dry weight ($r = 0.32$), and plant height ($r = 0.28$). In contrast, root length ($r = -0.15$) and leaf RWC ($r = -0.05$) showed very weak relationships. These results indicate that better physiological conditions are associated with higher antioxidant activity, which helps protect plant cells from ROS-induced damage (Gill & Tuteja, 2010).

Vitamin C showed moderate positive correlations with root fresh weight ($r = 0.50$), root dry weight ($r = 0.47$), root length ($r = 0.32$), and leaf RWC ($r = 0.32$). Conversely, moderate negative correlations were observed with chlorophyll content ($r = -0.51$), stem dry weight ($r = -0.52$), flower dry weight ($r = -0.46$), leaf fresh weight ($r = -0.35$), leaf dry weight ($r = -0.30$), and leaf number ($r = -0.30$). This pattern indicates that vitamin C accumulation tends to increase as a response to declining physiological conditions under stress. As a non-enzymatic antioxidant, vitamin C plays an essential role in ROS detoxification and protection of cellular components, thereby enhancing plant tolerance to abiotic stress (Foyer & Noctor, 2020).

Overall, the results demonstrate that drought and salinity stress significantly affect both physiological responses and phytochemical content in globe amaranth (*Gomphrena globosa* L.) accessions Sanur and Sibang. Increasing stress levels generally reduced physiological parameters such as chlorophyll content, vegetative growth, biomass, and leaf RWC, while phytochemical content changed as part of plant adaptive mechanisms. Differences in responses between accessions indicate genetic variation in stress tolerance. Furthermore, correlation analysis reveals that physiological and biochemical mechanisms are closely interconnected in enhancing plant tolerance to drought and salinity stress.

This study provides important information that physiological responses and phytochemical accumulation can serve as key indicators for evaluating the tolerance level of globe amaranth accessions to abiotic stress and may serve as a basis for selecting adaptive accessions suitable for cultivation under water-limited and high-salinity conditions.

CONCLUSION

The results of this study demonstrated that drought and salinity stress significantly affected the physiological responses of globe amaranth (*Gomphrena globosa* L.), as indicated by all observed variables. Differences in physiological responses between the Sanur and Sibang accessions indicate variation in their adaptive capacity to stress conditions, suggesting the important role of genetic factors in determining stress tolerance.

Drought and salinity stress also significantly influenced the phytochemical content of globe amaranth, including total phenolics, flavonoids, antioxidant activity, and vitamin C. Changes in phytochemical compounds indicate the activation of biochemical defense mechanisms in response to stress, with different response patterns observed among accessions according to their genetic characteristics.

Correlation analysis revealed a relationship between physiological parameters and phytochemical content under stress conditions. Phenolic content showed a strong negative correlation with most physiological growth parameters, while flavonoids, antioxidant activity, and vitamin C exhibited varying relationships with specific physiological traits. These findings indicate that physiological changes under stress are closely associated with phytochemical adjustments as part of plant adaptive mechanisms to drought and salinity stress.

ADVICE

Further research is recommended using a wider range of drought and salinity stress levels and longer treatment durations to obtain more comprehensive information on the physiological and phytochemical responses of globe amaranth (*Gomphrena globosa* L.).

Future studies should also include additional biochemical and molecular parameters, such as proline content, antioxidant enzyme activities (superoxide dismutase, catalase, and peroxidase), malondialdehyde (MDA) levels, and gene expression related to stress tolerance, in order to better understand plant adaptation mechanisms.

Accessions that demonstrate better physiological performance and are able to maintain phytochemical content under stress conditions have potential to be utilized as germplasm sources in cultivation and breeding programs aimed at developing varieties with improved tolerance to drought and salinity stress.

This study is expected to serve as a reference for future research on the utilization of globe amaranth as both an ornamental and functional plant rich in bioactive compounds, particularly under environmental conditions characterized by limited water availability and increased salinity.

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