

Effect of Water Stress and Foliar Application of Agrochemicals on Quality Parameters of Chia (*Salvia hispanica* L.)

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ABSTRACT

A field experiment was carried out during the *rabi* season of 2024–25 at the College of Agriculture, Agriculture University, Jodhpur (Rajasthan), to study the effect of water stress and foliar application of agrochemicals on quality attributes of chia (*Salvia hispanica* L.). The experiment was laid out in a split plot design with three irrigation levels, recommended irrigation (I_0), one irrigation skip (I_1)

and two irrigation skips (I_2) and four foliar-applied agrochemicals viz., control, thiourea, potassium nitrate and salicylic acid, replicated thrice. Results revealed that increasing water stress significantly reduced nitrogen, protein, oil content and swelling factor of chia seeds, while phosphorus and potassium contents were unaffected. Recommended irrigation recorded the highest nitrogen (3.471%), protein (21.70 g 100 g⁻¹), oil content (25.99%) and swelling factor (9.30 cc g⁻¹), whereas two irrigation skips resulted in the lowest values. Total phenol content increased under water stress, with the highest value under two irrigation skips (79.72 mg GAE 100 g⁻¹). Foliar application of potassium nitrate proved most effective in improving nitrogen (3.398%), protein (21.24 g 100 g⁻¹) and swelling factor (9.48 cc g⁻¹), while thiourea enhanced oil content (25.66%). The study concludes that potassium nitrate and thiourea mitigate water stress and improve chia seed quality under arid conditions.

Keywords Chia, Water stress, Agrochemicals, Seed quality.

INTRODUCTION

Chia (*Salvia hispanica* L.), an herbaceous annual species belonging to the family *Lamiaceae*, is often categorized as an underutilized or orphan crop; however, its resilience to adverse environmental conditions and its rich nutrient profile make it a valuable resource for strengthening food and nutritional security, particu-

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larly under water-limited environments. Originally domesticated nearly 4,500 years ago in Mexico and Guatemala, chia was a staple component of the diet of ancient Mesoamerican civilizations, owing to its ability to thrive in arid and semi-arid regions (Chaitanya *et al.* 2022).

The renewed global interest in chia during the late twentieth century was driven by extensive scientific evidence highlighting its functional and health-promoting attributes. This resurgence led to its reintroduction as a superfood, with Mexico, Argentina and Australia emerging as major producers (Busilacchi *et al.* 2013, Alenbrant *et al.* 2014). At present, chia seeds are widely incorporated into a variety of food products, including beverages, bakery items, breakfast cereals and functional foods (Mohd Ali *et al.* 2012, Barrientos *et al.* 2012). Dietary guidelines in several countries, including the United States, recommend chia seeds for regular consumption due to their high nutritional density and health benefits.

Nutritionally, chia seeds are characterized by a unique chemical composition when compared to conventional oilseeds such as sunflower and flax. The seeds contain approximately 25–30% oil, predominantly rich in α -linolenic acid, with omega-3 fatty acids constituting nearly 55% of the total fatty acid content (Ullah *et al.* 2016). In addition, chia seeds provide substantial amounts of dietary fiber (18–30%), protein (15–25%), carbohydrates and essential minerals such as calcium, phosphorus, potassium and magnesium, along with vitamins and bioactive compounds including phenolic acids and flavonoids (Muñoz *et al.* 2012). These attributes contribute to several health benefits, including improved lipid metabolism, reduced risk of cardiovascular diseases and anti-inflammatory effects, and make chia suitable for gluten-free diets.

Despite its classification as a drought-tolerant crop, chia growth, yield and seed quality are significantly influenced by soil moisture availability. Prolonged moisture deficit can decrease the concentration of unsaturated fatty acids, particularly omega-3 fatty acids, thereby compromising the nutritional quality of chia seeds (Herman *et al.* 2016). Although chia plants exhibit adaptive responses such as stomatal

regulation and osmotic adjustment through enhanced accumulation of proline and proteins, these mechanisms are often insufficient to completely offset the negative effects of severe water stress (Hartmann 2007, Sánchez-Rodríguez *et al.* 2012).

In recent years, foliar application of agrochemicals and bioregulators has emerged as an effective agronomic strategy to mitigate the adverse effects of water deficit stress. Exogenous application of compounds such as salicylic acid, thiourea and potassium nitrate has been reported to enhance water-use efficiency, improve plant-water relations and activate antioxidant defense mechanisms under deficit irrigation conditions (Harisha *et al.* 2023). Such interventions not only alleviate stress-induced physiological damage but also contribute to the maintenance of seed quality under limited water availability (Nawaz *et al.* 2016).

MATERIALS AND METHODS

The experiment took place at the College of Agriculture's Instructional Farm in Jodhpur (Rajasthan) during the *rabi* season of 2024-25. Geographically, the location is located between 26°15' N to 26°45' N latitude and 73°00' E to 73°29' E longitude, at an elevation of 231 meters above mean sea level (MSL). The area is in Rajasthan's agro-climatic zone IA, often known as the Arid Western Plains Zone. The experimental soil was sandy loam in texture, slightly alkaline (pH 8.31), and non-saline (EC 0.40 dS m⁻¹). The soil had low organic carbon (0.17%) and accessible nitrogen (150.53 kg ha⁻¹), but medium levels of available phosphorus (20.50 kg P₂O₅ ha⁻¹) and potassium (319.65 kg K₂O ha⁻¹).

The experiment was laid out in split plot design (SPD), comprising 12 treatment combinations and replicated three times. The main plot included three irrigation levels (recommended irrigation: I₀, one irrigation skips: I₁ and two irrigations skip: I₂). The subplots comprised foliar application of four different agrochemicals, including thiourea @ 2% (C₁), potassium nitrate @ 100 ppm (C₂), salicylic acid @ 100 ppm (C₃) and water spray as control (C₀). The chia variety used for the study was JC⁻¹.

At harvest, representative chia seed samples were

collected from each plot, dried, finely ground and analysed for nitrogen, phosphorus and potassium content using standard analytical procedures. Nitrogen content was estimated by the Kjeldahl method using a Micro-Kjeldahl Automatic Nitrogen Analyser (Piper, 1950), phosphorus by the vanadomolybdo-phosphoric acid yellow color method (Jackson 1973) and potassium by the flame photometer method (Bhargava and Raghupathi 1993). The nutrient concentrations were expressed as percentage on a dry weight basis.

Protein content of chia seeds was calculated by multiplying the nitrogen concentration (%) with a conversion factor of 6.25 as suggested by AOAC (1970) and expressed as g per 100 g of seed. Oil content was determined by extracting ground seed samples using an Automatic Soxhlet Extractor and the extracted oil was expressed as percentage of seed dry weight.

Total phenolic content of chia seeds was estimated by the Folin–Ciocalteu spectrophotometric method (Singleton and Rossi 1965). Seed powder was extracted with 80% methanol and an aliquot of the extract was reacted with Folin–Ciocalteu reagent and sodium carbonate. After incubation, absorbance was

recorded at 650 nm and total phenols were quantified using a gallic acid standard curve and expressed as mg gallic acid equivalents per 100 g of seed.

The swelling factor of chia seeds was determined by soaking one gram of seeds in 30 ml of distilled water for 24 hours, after which the volume occupied by the hydrated seeds was recorded. The swelling factor was expressed as cubic centimetres of water absorbed per gram of seed following Killedar *et al.* (2016).

RESULTS AND DISCUSSION

Effect of water stress

Water stress imposed through irrigation treatments significantly influenced nitrogen, protein, oil content, total phenols and swelling factor of chia seeds, while phosphorus and potassium contents remained unaffected. Recommended irrigation (I_0) recorded the highest nitrogen content (3.471%), which declined progressively with increasing water stress under one irrigation skip (I_1 , 3.385%) and two irrigation skips (I_2 , 3.160%) (Table 1). A similar decreasing trend was observed for protein and oil content, with maximum

Table 1. Effect of irrigation and agrochemicals on quality parameters.

Treatments	N content (%)	P content (%)	K content (%)	Quality parameters			
				Protein (g 100g ⁻¹)	Oil content (%)	Total phenol (mg GAE 100 g ⁻¹)	Swelling factor (cc g ⁻¹)
Irrigation							
I_0 : Recommended irrigations	3.471	0.443	0.302	21.70	25.99	70.24	9.30
I_1 : One irrigation skip	3.385	0.440	0.300	21.16	24.88	71.75	8.95
I_2 : Two irrigations skip	3.160	0.431	0.293	19.75	22.64	79.72	8.53
SEM±	0.010	0.006	0.003	0.06	0.27	0.38	0.10
CD at 5%	0.039	NS	NS	0.24	1.06	1.49	0.39
Agrochemicals (stress mitigating)							
C_0 : Control	3.275	0.429	0.292	20.47	23.12	76.90	8.37
C_1 : Thiourea	3.347	0.436	0.301	20.92	25.66	74.96	9.00
C_2 : KNO ₃	3.398	0.453	0.304	21.24	24.80	70.71	9.48
C_3 : Salicylic acid	3.335	0.434	0.296	20.85	24.43	73.03	8.85

Table 1. Continued.

Treatments	N content (%)	P content (%)	K content (%)	Quality parameters		Total phenol (mg GAE 100 g ⁻¹)	Swelling factor (cc g ⁻¹)
				Protein (g 100g ⁻¹)	Oil content (%)		
SEm ±	0.009	0.007	0.003	0.06	0.24	0.32	0.08
CD at 5%	0.028	NS	NS	0.18	0.73	0.94	0.25
Irrigation × Agrochemicals (stress mitigating)							
SEm±	0.016	0.011	0.006	0.10	0.42	0.55	0.15
CD at 5%	0.049	NS	NS	0.30	NS	1.64	0.43

values under I_0 (21.70 g 100 g⁻¹ protein and 25.99% oil) and minimum under I_2 (19.75 g 100 g⁻¹ protein and 22.64% oil), indicating the adverse impact of moisture stress on nitrogen assimilation and oil biosynthesis (Table 1). Similar results found by Ayerza and Coates (2009).

In contrast, total phenol content increased significantly with increasing water stress. The highest phenol content was recorded under two irrigation skips (I_2 , 79.72 mg GAE 100 g⁻¹), followed by I_1 (71.75 mg GAE 100 g⁻¹), while the lowest was observed under recommended irrigation (I_0 , 70.24 mg GAE 100 g⁻¹), suggesting enhanced synthesis of phenolic compounds as a stress response (Table 1). These findings are in line with Gill and Tuteja (2010), Gharibi *et al.* (2016) and Khoyerdi *et al.* (2016), where drought stress leads to increased phenolic compounds synthesis in plants. The swelling factor also decreased significantly with increasing water stress, recording the highest value under I_0 (9.30 cc g⁻¹) and the lowest under I_2 (8.53 cc g⁻¹), reflecting reduced water absorption capacity of seeds under moisture deficit (Table 1).

Effect of agrochemicals (stress mitigating)

Foliar application of stress-mitigating agrochemicals significantly influenced nitrogen content, protein, oil content, total phenols and swelling factor of chia seeds, whereas phosphorus and potassium contents were not significantly affected. Among agrochemicals, potassium nitrate (C_2) recorded the highest nitrogen content (3.398%), followed by thiourea (C_1 , 3.347%) and salicylic acid (C_3 , 3.335%), with the

lowest under control (C_0 , 3.275%). A similar trend was observed for protein content, which was highest under C_2 (21.24 g 100 g⁻¹) and lowest in control (20.47 g 100 g⁻¹) (Table 1). Potassium nitrate (C_2 , KNO₃) facilitates amino acid and protein biosynthesis by enhancing nitrate uptake and nitrogen assimilation (Fageria *et al.* 2009).

Oil content was significantly enhanced by agrochemical application, with thiourea (C_1) recording the maximum oil content (25.66%), followed by potassium nitrate (C_2 , 24.80%) and salicylic acid (C_3 , 24.43%), while the control recorded the lowest oil content (23.12%) (Table 1). Mahmoud and Taha (2018) found similar results, demonstrated that sulfur improves oil synthesis. In contrast, total phenol content was highest in the control (76.90 mg GAE 100 g⁻¹) and lowest under potassium nitrate application (70.71 mg GAE 100 g⁻¹), indicating effective stress alleviation by agrochemicals, thereby reducing phenolic accumulation. The swelling factor was significantly improved by potassium nitrate (C_2 , 9.48 cc g⁻¹), followed by thiourea and salicylic acid, whereas the lowest swelling factor was observed under control (8.37 cc g⁻¹) (Table 1). These results are supported by studies of Rahimi *et al.* (2013), Ahl *et al.* (2014) and Harisha *et al.* (2023).

Interaction effect

The interaction between irrigation levels and stress-mitigating agrochemicals significantly influenced nitrogen content, protein content, total phenols and swelling factor of chia seeds, while the interaction effect on oil content was non-significant. The highest

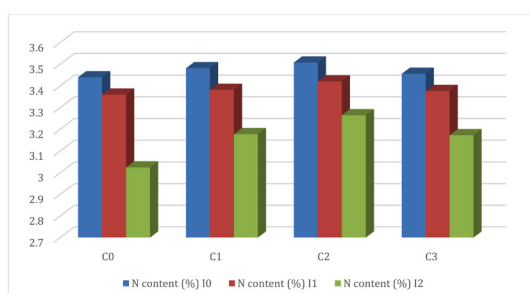


Fig. 1. Interaction effect of irrigation and agrochemicals on nitrogen content (%) of Chia.

nitrogen content (3.508%) was recorded under the combination of recommended irrigation with potassium nitrate (I_0C_2), followed by I_0C_1 and I_0C_3 , whereas the lowest nitrogen content was observed under two irrigation skips without agrochemical application (I_2C_0) (Fig. 1). Similarly, the maximum protein content (21.93 g 100 g⁻¹) was recorded under I_0C_2 , while the minimum (18.91 g 100 g⁻¹) occurred under I_2C_0 , highlighting the combined negative effect of severe water stress and absence of stress mitigation (Fig. 2). The similar trend was reported by Harisha *et al.* (2023), where untreated, water-stressed chia plants suffered major declines in both yield and quality.

Total phenol content was highest under I_2C_0 (85.47 mg GAE 100 g⁻¹), indicating maximum stress-induced phenolic accumulation, whereas the lowest phenol content was observed under I_0C_2 (68.00 mg GAE 100 g⁻¹), reflecting efficient stress alleviation under adequate moisture and potassium nitrate application (Fig. 3). This pattern aligns with the findings of

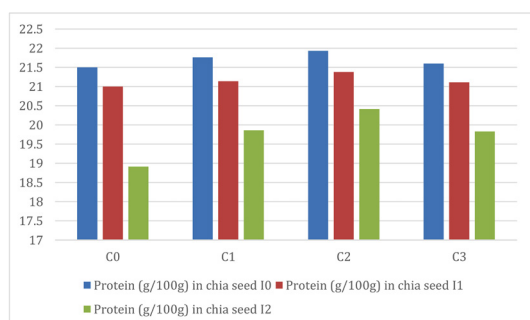


Fig. 2. Interaction effect of irrigation and agrochemicals on protein content (g 100g⁻¹) of Chia.

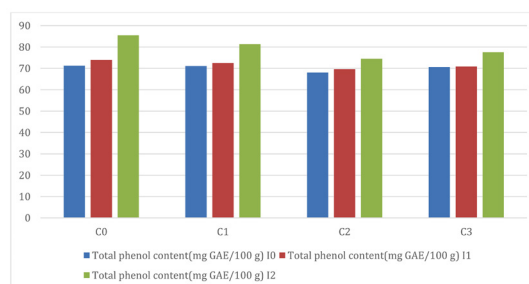


Fig. 3. Interaction effect of irrigation and agrochemicals on total phenol content mg GAE 100 g⁻¹ content of Chia.

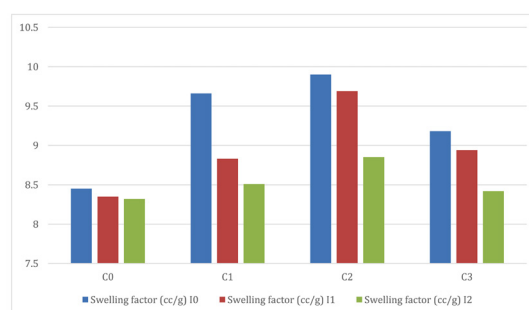


Fig. 4. Interaction effect of irrigation and agrochemicals on swelling factor (cc g⁻¹) of Chia.

Gill and Tuteja (2010), who reported increased phenol synthesis as a defense mechanism under drought. The swelling factor was also significantly influenced by interaction effects, with the highest value recorded under I_0C_2 (9.90 cc g⁻¹) and the lowest under I_2C_0 (8.32 cc g⁻¹) (Fig. 4).

CONCLUSION

It is concluded that adequate irrigation is essential for maintaining superior seed quality of chia, as recommended irrigation recorded the highest nitrogen content, protein, oil content and swelling factor. Increasing moisture stress through skipped irrigations markedly deteriorated seed quality, while enhancing phenolic accumulation as a stress response. However, foliar application of stress-mitigating agrochemicals, particularly potassium nitrate, effectively alleviated the adverse effects of water stress. Thiourea was found to be especially effective in enhancing oil content under both normal and stress conditions. Therefore,

the integration of adequate irrigation with foliar application of potassium nitrate emerges as a practical and efficient management strategy for improving seed quality of chia under arid and semi-arid conditions.

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