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Effect of water stress and silica on growth parameters of Fenugreek (*Trigonella foenum-graecum* L.)

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Abstract

A field experiment was conducted during *rabi*, 2025-26 at the Instructional Farm, Department of Agronomy, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan, to study the effect of water stress stages and silica levels on growth parameters of fenugreek (*Trigonella foenum-graecum* L.). The experiment was laid out in a factorial randomized block design with four water stress stages, namely control (no stress), water stress at branching (25 DAS), water stress at flowering (55 DAS) and water stress at pod formation (85 DAS) and four silica levels, namely control, 50, 100 and 150 kg ha⁻¹, with three replications. Results showed that control (no stress) recorded maximum plant height at harvest (85.79 cm), dry matter accumulation at harvest (21.08 g plant⁻¹), leaf area at harvest (24.97 dm²), crop growth rate during 60-90 DAS (10.24 g m⁻² day⁻¹), relative growth rate during 60-90 DAS (0.0321 g g⁻¹ day⁻¹) and number of effective root nodules (24.12 plant⁻¹). Among silica levels, application of 150 kg ha⁻¹ recorded the highest plant height at harvest (85.16 cm), dry matter accumulation at harvest (20.49 g plant⁻¹), leaf area at harvest (23.45 dm²), crop growth rate during 30-60 DAS (4.89 g m⁻¹ day⁻¹), net assimilation rate during 90 DAS to harvest (0.0198 g dm⁻² day⁻¹), earliest flowering (50.25 days), earliest physiological maturity (112.45 days) and maximum effective root nodules (24.02 plant⁻¹), remaining at par with 100 kg ha⁻¹ for several parameters. The study established that adequate soil moisture and silica nutrition markedly improved vegetative growth and physiological efficiency of fenugreek under Udaipur conditions.

Keywords: Fenugreek, water stress, silica, growth parameters, dry matter accumulation, crop growth rate, relative growth rate

Introduction

Fenugreek (*Trigonella foenum-graecum* L.), commonly known as methi, is one of the oldest cultivated crops and an important winter-season legume spice of India. It belongs to the family Fabaceae and is widely valued for its seed, foliage, nutritional richness and medicinal properties. Fenugreek seeds are rich in protein, lipids, mucilage, saponins and mineral constituents and the crop occupies a notable place among seed spices grown in arid and semi-arid regions. India has about 1.47 lakh ha under fenugreek with a production of 226.85 thousand tonnes and an average productivity of 1453 kg ha⁻¹, while Rajasthan is one of the major producing states. However, crop productivity is often restricted by water scarcity during critical growth stages, especially in semi-arid production systems. Since growth parameters such as plant height, dry matter accumulation, leaf area and growth rates determine the photosynthetic efficiency and productive capacity of the crop, any factor affecting vegetative growth can substantially influence final performance.

Proper irrigation scheduling is therefore essential for maintaining favorable plant water relations, cell expansion, assimilate production and nodulation. In addition, silicon is considered a beneficial element for plants because it improves structural rigidity, water relations and tolerance to abiotic stresses, including moisture deficit. Under water stress conditions, silicon may help sustain physiological processes and reduce transpirational losses, thereby improving crop growth.

In view of these considerations, the present study was undertaken to assess the effect of water stress stages and silica levels on the growth parameters of fenugreek under Udaipur conditions.

Materials and Methods

The field experiment was conducted during *rabi*, 2025-26 at block C6, Instructional Farm, Department of Agronomy, Rajasthan College of Agriculture, MPUAT, Udaipur, Rajasthan. The experimental site falls under agro-climatic zone IVa, Sub-Humid Southern Plain and Aravalli Hills of Rajasthan, situated at 24°58' N latitude and 73°70' E longitude with an altitude of 582.18 m above mean sea level. During crop growth, the maximum and minimum temperatures ranged from 22.8 to 35.7°C and 6.3 to 14.7°C, respectively, and only 0.2 mm rainfall was received during the crop season.

The soil was clay-loam in texture, slightly alkaline in reaction (pH 7.7), low in organic carbon (0.70 per cent) and available nitrogen (276.58 kg ha⁻¹), medium in available phosphorus (21.06 kg ha⁻¹) and high in available potassium (291.52 kg ha⁻¹). The experiment comprised sixteen treatment combinations involving four water stress stages, namely control (W₀), water stress at branching at 25 DAS (W₁), water stress at flowering at 55 DAS (W₂) and water stress at pod formation at 85 DAS (W₃), along with four silica levels, namely control (S₀), 50 kg ha⁻¹ (S₁), 100 kg ha⁻¹ (S₂) and 150 kg ha⁻¹ (S₃). These treatments were tested in a factorial randomized block design with three replications.

Fenugreek variety PRM-45 was sown on 17 November 2025 using a seed rate of 25 kg ha⁻¹ at a spacing of 30 cm × 10 cm. Silica was applied as basal dose according to treatment, while water stress was imposed by skipping irrigation at the designated crop stages. Observations were recorded on plant population, plant height, dry matter accumulation, leaf area, crop growth rate, relative growth rate, net assimilation rate, days to flower initiation, days to physiological maturity and effective root nodules using standard procedures. The data were analysed statistically through analysis of variance, and treatment significance was tested at the 5 per cent level.

Results and discussion

Water stress stages: Plant population at 20 DAS and at harvest was not significantly influenced by the different water stress stages, showing that crop establishment remained uniform across all treatments. This indicates that the moisture stress imposed at later stages did not interfere with germination or early seedling survival. Because the initial plant stand remained unchanged, the subsequent differences observed in growth traits can be attributed mainly to the effect of water regime rather than to variation in crop establishment.

At 60 DAS, plant height was highest under control at 40.45 cm, followed closely by pod formation stress at 39.83 cm and flowering stress at 39.74 cm, while branching stress recorded the lowest height of 35.61 cm. At 90 DAS, control again produced the tallest plants at 78.56 cm, compared with 76.82 cm under pod formation stress, 75.31 cm under flowering stress and 72.46 cm under branching stress. At harvest, control recorded the maximum plant height of 85.79 cm, while pod formation, flowering and branching stress recorded 81.68, 80.72 and 78.45 cm, respectively. The results indicate that early moisture stress at branching had the greatest suppressive effect on height because it occurred during active vegetative expansion. Adequate moisture under control helped maintain turgor, cell division and internodal elongation, resulting in the tallest plants (Bazzazi *et al.*, 2013) [3]. Dry matter accumulation also followed the same trend. At harvest, control recorded the highest dry matter accumulation of 21.08 g plant⁻¹ followed by pod formation stress at 19.75 g plant⁻¹, flowering stress at 18.11 g plant⁻¹ and branching stress at 16.95 g plant⁻¹. At 90 DAS, the values were 13.99, 13.32, 12.45 and 11.69 g plant⁻¹, respectively, for control, pod formation, flowering

and branching stress. These values show that moisture stress reduced biomass formation progressively, with branching stress causing the maximum reduction because it affected canopy formation at a critical stage. Reduced soil moisture likely limited photosynthesis, leaf expansion and assimilate supply, which lowered total dry matter accumulation (Badawy *et al.*, 2025) [2].

Leaf area at harvest was highest under control at 24.97 dm², while branching, flowering and pod formation stress reduced it to 21.81, 20.49 and 20.53 dm², respectively. At 90 DAS, control recorded 46.88 dm², compared with 42.54, 38.97 and 45.54 dm² under branching, flowering and pod formation stress. The larger leaf area under control indicates better canopy development and sustained leaf function throughout the crop period. In contrast, stress reduced leaf expansion and hastened senescence, thereby lowering the photosynthetic surface available for biomass production.

Crop growth rate was highest under control during 60-90 DAS at 10.24 g m⁻² day⁻¹, followed by pod formation stress at 9.62 g m⁻² day⁻¹, flowering stress at 8.60 g m⁻² day⁻¹ and branching stress at 8.12 g m⁻² day⁻¹. During 90 DAS to harvest, the values were 7.88, 7.14, 6.29 and 5.84 g m⁻² day⁻¹, respectively. Relative growth rate also remained highest under control during 60-90 DAS at 0.0321 g g⁻¹ day⁻¹, compared with 0.0312, 0.0296 and 0.0285 g g⁻¹ day⁻¹ under pod formation, flowering and branching stress. These results indicate that non-stressed plants used light and assimilates more efficiently for biomass gain. Branching stress was more damaging because it reduced growth efficiency for a longer period.

Net assimilation rate was also maximum under control in the early and mid-growth stages. At 30-60 DAS, control recorded 0.0170 g dm⁻² day⁻¹, compared with 0.0164-0.0165 under pod formation and flowering stress and 0.0133 under branching stress. During 60-90 DAS, control recorded 0.0328 g dm⁻² day⁻¹, while pod formation, branching and flowering stress recorded 0.0323, 0.0268 and 0.0261 g dm⁻² day⁻¹. This shows that moisture stress lowered the crop's ability to convert intercepted radiation into dry matter. Lower stomatal conductance and weaker leaf activity under stress likely caused the reduced assimilation rate.

Water stress at branching caused the earliest flowering at 50.42 days, while control flowered at 51.83 days. Flowering stress and pod formation stress recorded 51.92 and 52.17 days, respectively. Physiological maturity was earliest under flowering stress at 114.24 days, compared with 115.48, 117.38 and 119.03 days under pod formation, branching and control. This indicates that water stress shortened crop duration as a stress-escape mechanism. However, earlier flowering and maturity generally reduce the time available for biomass accumulation and seed filling, which can lower productivity.

The number of effective root nodules was highest under control at 24.12 plant⁻¹, followed by pod formation stress at 23.15, flowering stress at 22.38 and branching stress at 21.26. This shows that adequate moisture favoured rhizobial activity and nodule formation. Water deficit, especially at branching, likely reduced root infection and nodule initiation because a dry rhizosphere is unfavorable for symbiotic nitrogen fixation (Fawaz and Mohammad, 2013) [7]. As a result, the crop maintained better nodulation under control than under stressed conditions.

Silica levels: Plant population was not significantly affected by silica levels, but values increased slightly from 10.55 plants m⁻¹ in the control to 11.07 plants m⁻¹ under 150 kg ha⁻¹ at 20 DAS, and from 9.05 to 9.37 plants m⁻¹ at harvest. This confirms that silica did not affect crop stand, but rather influenced later growth processes. Since emergence was uniform, the effect of silica

became visible mainly in plant height, biomass and canopy development.

Plant height improved steadily with silica application. At 30 DAS, 150 kg ha⁻¹ produced the tallest plants at 16.35 cm, compared with 16.15 cm at 100 kg ha⁻¹, 15.85 cm at 50 kg ha⁻¹ and 14.95 cm in the control. At harvest, the corresponding values were 85.16, 85.12, 80.69 and 75.67 cm, respectively. The higher silica levels therefore promoted stronger vegetative growth by improving turgidity, structural strength and leaf erectness. This structural advantage likely helped plants intercept more light and sustain growth for a longer time (Bhatt *et al.*, 2023) ^[5]. Similar structural enhancements were reported by El-Okkiah *et al.*, (2022) ^[6], who observed that silica application distinctly improved overall water stress tolerance, resulting in superior performance in plant height and leaf area even under strict moisture deficit conditions.

Dry matter accumulation also increased with silica dose. At harvest, 150 kg ha⁻¹ recorded the highest dry matter accumulation of 20.49 g plant⁻¹ followed by 100 kg ha⁻¹ at 19.71 g plant⁻¹, 50 kg ha⁻¹ at 18.47 g plant⁻¹ and control at 17.21 g plant⁻¹. At 90 DAS, the values were 13.55, 13.51, 12.79 and 11.59 g plant⁻¹, respectively. This suggests that silica supported biomass production by improving photosynthetic efficiency and reducing stress-related water loss. The trend clearly indicates that the highest silica dose was most effective in sustaining dry matter formation, which strongly aligns with the findings of Begam and Nithyasri (2025) ^[4], who noted that optimal silica treatments intensely enhanced overall growth components and consistently pushed total biological yield upward.

Leaf area increased with silica application as well. At harvest, 150 kg ha⁻¹ produced the maximum leaf area of 23.45 dm², followed by 100 kg ha⁻¹ at 22.75 dm², 50 kg ha⁻¹ at 21.49 dm² and control at 20.10 dm². At 90 DAS, leaf area reached 45.07 dm² under 150 kg ha⁻¹, compared with 44.79, 43.03 and 41.05 dm² in 100, 50 and control treatments. This shows that silica improved canopy size and maintained leaf function for a longer duration (Ahmed *et al.*, 2011) ^[1]. A larger canopy would have provided better interception of solar radiation and supported greater biomass accumulation.

Crop growth rate was highest under 150 kg ha⁻¹ during 30-60

DAS at 4.89 g m⁻² day⁻¹, while 100 kg ha⁻¹ recorded the highest value during 60-90 DAS at 9.75 g m⁻² day⁻¹. During 90 DAS to at harvest, 150 kg ha⁻¹ again recorded the highest value at 7.71 g m⁻² day⁻¹. Relative growth rate also followed a similar pattern, with 150 kg ha⁻¹ recording 0.0214, 0.0313 and 0.0277 g g⁻¹ day⁻¹ at different stages. These results show that silica improved the efficiency of biomass production over the crop period. The close values of 100 and 150 kg ha⁻¹ indicate that both were effective, but 150 kg ha⁻¹ was generally superior for overall growth performance.

Net assimilation rate was also highest under 150 kg ha⁻¹ in most stages. The values were 0.0168, 0.0319 and 0.0198 g dm⁻² day⁻¹ during 30-60, 60-90 DAS and 90 DAS to at harvest, respectively. This shows that silica improved the crop's physiological efficiency in converting light into dry matter. The effect can be linked to better leaf erectness, lower transpiration loss and sustained photosynthetic activity under silicon nutrition. Therefore, silica acted as a growth-promoting input that strengthened the crop's source capacity.

Silica also slightly reduced days to flowering and maturity. At 150 kg ha⁻¹, flowering occurred at 50.25 days and maturity at 112.45 days. These values were earlier than the control, which flowered at 53.58 days and matured at 121.23 days. The earlier phenology suggests that silica helped the crop develop more efficiently and complete its growth cycle in a more synchronized manner. This should be viewed as improved crop vigour rather than stress-induced shortening of duration.

The highest number of effective root nodules was recorded at 150 kg ha⁻¹ with 24.02 nodules plant⁻¹, while the control had only 20.39 nodules plant⁻¹. This indicates that silica improved root health and probably encouraged better symbiotic nitrogen fixation. A stronger root system would have supported better nutrient uptake and growth. Furthermore, as concluded by Kankia *et al.*, (2025) ^[8], integrated treatments including silicon markedly increase nutrient uptake, reduce oxidative stress markers, and synergistically enhance deep resilience under water deficit conditions. Overall, silica at 150 kg ha⁻¹ consistently produced the best growth response across almost all parameters.

Table 1: Effect of water stress and silica on plant height, dry matter accumulation and leaf area

Treatments	Plant height (cm)				Dry matter accumulation (g plant ⁻¹)				Leaf area (dm ²)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
A. Water stress stages												
Control (No stress)	15.65	40.45	78.56	85.79	0.40	4.77	13.99	21.08	6.20	26.94	46.88	24.97
Water stress at branching (25 DAS)	15.58	35.61	72.46	78.45	0.41	4.39	11.69	16.95	6.15	22.66	42.54	21.81
Water stress at flowering (55 DAS)	16.14	39.74	75.31	80.72	0.41	4.71	12.45	18.11	6.17	26.37	38.97	20.49
Water stress at pod formation (85 DAS)	15.92	39.83	76.82	81.68	0.42	4.66	13.32	19.75	6.15	26.59	45.54	20.53
S.Em.±	0.30	0.59	1.26	1.44	0.01	0.08	0.24	0.38	0.09	0.36	0.60	0.38
C.D. (P=0.05)	NS	1.69	3.65	4.17	NS	0.24	0.70	1.09	NS	1.05	1.74	1.11
B. Silica levels												
Control	14.95	35.71	70.49	75.67	0.38	4.33	11.59	17.21	5.70	24.12	41.05	20.10
50 kg ha ⁻¹	15.85	38.81	75.10	80.69	0.41	4.63	12.79	18.47	6.22	25.39	43.03	21.49
100 kg ha ⁻¹	16.15	40.55	78.76	85.12	0.42	4.74	13.51	19.71	6.34	26.50	44.79	22.75
150 kg ha ⁻¹	16.35	40.58	78.80	85.16	0.43	4.83	13.55	20.49	6.40	26.56	45.07	23.45
S.Em.±	0.30	0.59	1.26	1.44	0.01	0.08	0.24	0.38	0.09	0.36	0.60	0.38
C.D. (P=0.05)	0.85	1.69	3.65	4.17	0.03	0.24	0.70	1.09	0.25	1.05	1.74	1.11

Table 2: Effect of water stress and silica on crop growth rate, relative growth rate and net assimilation rate

Treatments	Crop Growth rate (g m ⁻² day ⁻¹)				Relative Growth Rate (g g ⁻¹ day ⁻¹)				Net Assimilation Rate (g dm ⁻² day ⁻¹)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
A. Water stress stages												
Control (No stress)	4.86	10.24	7.88	4.86	0.0213	0.0321	0.0281	0.0213	0.0170	0.0328	0.0140	0.0170
Water stress at branching (25 DAS)	4.42	8.12	5.84	4.42	0.0200	0.0285	0.0236	0.0200	0.0133	0.0268	0.0167	0.0133
Water stress at flowering (55 DAS)	4.77	8.60	6.29	4.77	0.0211	0.0296	0.0245	0.0211	0.0165	0.0261	0.0175	0.0165
Water stress at pod formation (85 DAS)	4.71	9.62	7.14	4.71	0.0209	0.0312	0.0266	0.0209	0.0164	0.0323	0.0255	0.0164
S.Em.±	0.09	0.25	0.39	0.09	0.0003	0.0004	0.0009	0.0003	0.0004	0.0008	0.0006	0.0004
C.D. (P=0.05)	0.27	0.72	1.11	0.27	0.0009	0.0012	0.0026	0.0009	0.0012	0.0022	0.0016	0.0012
B. Silica levels												
Control	4.39	8.07	6.25	4.39	0.0198	0.0284	0.0243	0.0198	0.0143	0.0257	0.0167	0.0143
50 kg ha ⁻¹	4.69	9.06	6.31	4.69	0.0208	0.0302	0.0245	0.0208	0.0157	0.0285	0.0181	0.0157
100 kg ha ⁻¹	4.79	9.75	6.89	4.79	0.0211	0.0314	0.0263	0.0211	0.0164	0.0318	0.0190	0.0164
150 kg ha ⁻¹	4.89	9.70	7.71	4.89	0.0214	0.0313	0.0277	0.0214	0.0168	0.0319	0.0198	0.0168
S.Em.±	0.09	0.25	0.39	0.09	0.0003	0.0004	0.0009	0.0003	0.0004	0.0008	0.0006	0.0004
C.D. (P=0.05)	0.27	0.72	1.11	0.27	0.0009	0.0012	0.0026	0.0009	0.0012	0.0022	0.0016	0.0012

Table 3: Effect of water stress and silica on growth parameters of fenugreek

Treatments	Days to flower initiation	Days to physiological maturity	Number of effective nodules	Effective nodules weight (mg plant ⁻¹)
A. Water stress stages				
Control (No stress)	51.83	119.03	24.12	39.10
Water stress at branching (25 DAS)	50.42	117.38	21.26	38.69
Water stress at flowering (55 DAS)	51.92	114.24	22.38	38.38
Water stress at pod formation (85 DAS)	52.17	115.48	23.15	40.46
S.Em.±	0.40	0.89	0.43	0.56
C.D. (P=0.05)	1.16	2.57	1.24	NS
B. Silica levels				
Control	53.58	121.23	20.39	38.63
50 kg ha ⁻¹	51.83	117.63	22.55	39.55
100 kg ha ⁻¹	50.67	114.82	23.94	39.33
150 kg ha ⁻¹	50.25	112.45	24.02	39.13
S.Em.±	0.40	0.89	0.43	0.56
C.D. (P=0.05)	1.16	2.57	1.24	NS

Conclusion

The study showed that growth parameters of fenugreek were markedly influenced by water stress stages and silica levels. Control (No stress) treatment produced the best growth performance, whereas water stress at branching was most detrimental to vegetative growth and flowering stress accelerated crop maturity. Among silica levels, 150 kg ha⁻¹ gave the highest values for most growth parameters and remained statistically at par with 100 kg ha⁻¹ in several cases. Thus, maintaining adequate soil moisture along with higher silica application can be considered an effective strategy to improve growth and physiological performance of fenugreek under Udaipur conditions.

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