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Effect of Sulphur Application on Yield, Nutrient Uptake and Quality of Chickpea (*Cicer arietinum* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted at Pulse Research Station in Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra from the period of Rabi 2020-21 to 2022-23 to study the effect of sulphur application on yield, Nutrient Uptake and quality of Chickpea (Cicer arietinum L.). The experiment was laid out in Randomized block design (RBD) with 9 treatments and 3 replications. The study revealed that the application of sulphur application is significantly influenced the yield, Nutrient uptake and quality. The highest Grain yield in Kilograms per hectare (2418 kg ha-1) and straw yield (3016 kg ha-1) were recorded with the application of S @30 kg ha-1 through Bentonite sulphur along with Recommended dose of fertilizers and it was found significantly superior over all the treatments. Similarly maximum N, P, K, S and micronutrient uptake and improved quality were observed with application of @ 30 kg ha-1 through Bentonite sulphur along with Recommended dose of fertilizers followed by the treatment of application of S @ 30 kg ha-1 through Gypsum + RDF.

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1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) is the most important grain legume in the world after dry beans and dry peas. Its cultivation is mainly confined to Asia with 90 per cent of the global area and production. Besides Asia it is also grown in North and Central America, the Mediterranean region, the west Asia and North Africa (WANA) region and Eastern Africa. India is top pulse producing country in the world. Among pulses chickpea ranks third in the world. The total area under pulses in India has increased from 19 million hectares in 1950-51 to 29 million hectares in 2016-17. The total pulse production in India was 18.43 million tonnes (2014-15), 19.41 million tonnes (2015-16) and 22.95 million tonnes (2016-17) [1]. Thus, of the total production of legumes, chickpea represented 18.63%.Of the total production of pluses worldwide, India contributes from 27.53% to 59.67% [2].

Chickpea is an important food legume commodity and have a diverse use with specific consumer preference in the global market. Chickpea production in India has peaked to all time high at 11.23 million tons during 2017-2018 (MoAF&W, 2019) and it was sustained to 10.32 million tons (MoAF&W 2019) which has ushered self sufficiency for this main pulse crop in India.With negligible share of private sector in this crop ,this remarkable achievement could be attained with the efforts of chickpea breeders from the National Agricultural Research System (NARS), policy makers at the center and state ministers and personnel of the seed production and certification system.

During 2021-22 (fourth estimate), chickpea production of India was million tonnes from an acreage of 10.91 million ha. With a productivity of 12.6 q./ha (DES 2023, MOAF&W, GoI). Chickpea solely contributes nearly 50% of the Indian pulse production. States like Maharashtra (25.97%) contribution to national production), Madhya Pradesh (18.59%), Rajasthan (20.65%), Gujarat (10.10%) and Uttar Pradesh (5.64%) are major chickpea producing states of India. Chickpea has a diverse consumption pattern in the Indian market. The food products include immature green grain (desi type), mature grain (desi/kabuli type), flour of mature grain (besan, desi type), roasted grain (desi type), flour of roasted grain (shattu, desi type), split grain or pulse (dahl, desi type), snacks (namkeens, desi and kabuli type), flakes (desi type), baked products (from flour, desi type), sweets/savories (from flour, desi type) and various tertiary processed products (cuisines). With the increasing trend of the market of products based on plant protein (protein isolates etc.), importance of chickpea to the processing sector has enhanced further. The global chickpeas market grew from $13.93 billion in 2022 to $ 14.9 billion in 2023 at a compound annual growth rate (CAGR) of 7.0%. The chickpeas market is expected to grow $19.19 billion in 2027 at a CAGR of 6.5%. During 2021, INDIA'S share in global Export of chickpea wa 5.87% (Rank 5, Export Volume 94.08 MKGs) and share in import was 12.51% (Rank 2, Import Volume 240.97 MKGs). Share of India in global chickpea production was 73.46% during 2020 (Tridge,2023).

Sulphur is the 4th major essential plant nutrient after N, P and K due to its role in the synthesis of proteins, vitamins, enzyme and flavoured compounds in plant. Its amount required by the plant is similar to phosphorus but less than N and K. About 90% of plant sulphur is present in amino acids *viz*., Methionine, Cystine, and Cysteine. These amino acids are the building blocks of protein. Sulphur is associated with production of crops of superior nutritional and market quality. Sulphur deficiencies are reported from over 70 countries worldwide including India. Soil Sulphur deficiency is increasing due to the use of high-grade S-free fertilizers, cultivation of high- yielding varieties and lack of industrial activity [3].

The rapid depletion of sulphur in Indian and Maharashtra soil pose a significant challenge to agriculture Productivity.This depletion is primarily driven by intensive multiple cropping systems that utilize high-yielding fertilizer-responsive varieties. Use of sulphur containing fertilizers in soil will be helpful to the farmers in improving growth of plant, increasing protein content, yield of chickpea. Sulphur, in chickpea, mainly influences the protein content. Sulphur helps towards conversion of nitrogen into protein in pulse crops. Sulphur also improves the S containing amino acid in crop and thus enhances the protein content [4].

In Maharashtra state, isolated attempts were made to work out a critical level of sulphur in the soils and plants. In Indian soils sulphur deficiency has been noticed 32.9 % [5], while in Maharashtra sulphur deficiency recorded to the extent of 37.48 % while in Vidarbha it was noticed 25.76 [6]. So, it is essential to evaluate the effect of sulphur application on soil fertility, yield, nutrient uptake and quality of chickpea in black soil. The information generated through this investigation will be helpful to apply the sulphur fertilizers to chickpea crop in Vertisols.

Keeping all the above facts in view, the present investigation was undertaken with the objectives to Determine the critical level of sulphur for optimal chickpea yield.

2. MATERIALS AND METHODS

The experiment was conducted to study the sulphur requirement of Chickpea crop and the Variety of the crop is Jaki-9218. The soil was analysed for soil properties, plant and seed samples were analysed for nutrient uptake and quality of chickpea crop. The field experiment was conducted at Pulse Research Unit, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola during rabi season 2020-21 to 2022-23. And the date of sowing is 17/11/2020, 10/11/2021 and 13/11/2022 and the date of harvesting is 05/02/21,10/03/22 and 12/03/23 respectively. The site is situated at the subtropical region at 22^0 42' North latitude and 77^0 02' East longitude and at an altitude of 307.42 m above mean sea level. Initial composite soil sample was collected at the depth of 15-20 cm from the experimental site and analyzed for soil properties.

The experimental site was slightly alkaline in reaction (7.96), non-saline (0.24 dS m^{-1}), medium in organic carbon (5.28 g kg^{-1}), calcareous in nature (6.87%), low in available N (188.16 kg ha^{-1}), low in available P (13.65 kg ha^{-1}), very high in available K (581.2 kg ha^{-1}), deficient in available S (9.82 mg kg^{-1}) and sufficient in DTPA – Zn(1.64 mg kg^{-1}), Fe(9.37 mg kg^{-1}), Cu(1.60 mg kg^{-1}) and Mn (8.22 mg kg^{-1}). Treatment details were as T_1 was Absolute Control, T_2 is S-free Recommended dose of fertilizer (N, P_2O_5, K_2O through Urea, Di-Ammonium Phosphate, Muriate of potash), T_3 was RDF (N, P_2O_5, K_2O through Urea, Single Super Phosphate, Muriate Of Potash), T_4 was T_2 + S @ 10 kg ha^{-1} through Bentonite-Sulphur, T_5 was T_2 + S @ 20 kg ha^{-1} through Bentonite-Sulphur, T_6 was T_2 + S @ 30 kg ha^{-1} through Bentonite-Sulphur, T_7 was T_2 +S @ 10 kg ha^{-1} through Gypsum, T_8 was T_2 +S @ 20 kg ha^{-1} through Gypsum, T_9 was T_2 + S @ 30 kg ha^{-1} through Gypsum. The recommended dose of NPK &S fertilizer used were 20:60:40:30. The Five plant samples were collected at maturity stage. The Five plant samples of shoot and grain were air dried and then oven dried at 105°C. The treatment wise samples were ground by using grinding mill and stored with proper labelling in brown paper bags. The powered samples of straw and grain were used for the chemical analysis of N, P, K, S and micronutrient content which were estimated using modified Kjeldahl's method (AOAC,1995), phosphorous by Ammonium molybdate vanadate [7], potassium by using Flame Photometer [8], sulphur was estimated from di-acid extract turbidimetrically using Spectrophotometer (Chesnin and Yien 1950) and micro nutrients by using AAS [9]. The test of statistically significance of the experimental data was carried out as per procedure described by Panse et al [10].

Chart 1. Initial soil status of the experiment

Sr. No.	Particulars	Values
1	pH	7.96
2	EC (dS m^{-1})	0.24
3	Organic carbon (g Kg^{-1})	5.28
4	$CaCO_3$ (%)	6.87
5	Available N (kg ha^{-1})	188.16
6	Available P (kg ha^{-1})	13.65
7	Available K (kg ha^{-1})	581.2
8	Available S (mg kg^{-1})	9.82
9	Fe (mg kg^{-1})	9.37
10	Zn (mg kg^{-1})	1.64
11	Mn (mg kg^{-1})	8.22
12	Cu (mg kg^{-1})	1.60

3. RESULTS AND DISCUSSION

3.1 Yield of Chickpea

The data pertaining to Grain yield of chickpea was influenced significantly (Table 1). The significantly higher Grain yield (2418 Kg ha^{-1}) of chickpea was recorded with the application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF (T_6) and it was found to be on par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9), S @ 20 kg ha $^{-1}$ through Bentonite sulphur + RDF (T_5). The lowest Grain yield of chickpea (1488 Kg ha^{-1}) was recorded in absolute control. Our results are in line with Srinivasulu et al. [11], reported the effect of sulphur application in increasing the Grain and straw yield of chickpea, while Das et al.[4], reported increase in growth, plant yield and yield attributing characters of chickpea with increasing sulphur doses. The increasing in yield might be due to the fact that S perform many physiological functions in Cysteine, methionine and chlorophyll Synthesis.Thus these bioactivities of sulphur might have played important role in improving yield attributing characters and yield of chickpea. Similar results were also given by Patel et al [12], Fayaz et al. [13] and Bhuriya et al. [14].

Data in (Table 2). The significantly higher straw yield (3016 Kg ha^{-1}) of chickpea was observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF (T_6) and it was found to be on par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9), S @ 20 kg ha $^{-1}$ through Bentonite sulphur + RDF (T_5), S @ 20 kg ha^{-1} through Gypsum + RDF (T_8). The lowest straw yield of chickpea (1825 Kg ha^{-1}) was recorded in control treatment T_1. Jadeja et al. [15], also reported increased Grain and straw yield of chickpea with sulphur application as compared to control. Similar finding of increased stover yield with sulphur application were also given by Srinivasulu et al. [11] Fayaz et al. [13] and Bhuriya et al. [14].

3.2 Nutrient Uptake

Data pertaining to Nitrogen uptake is given in (Table 3). There is significant improvement of nitrogen uptake with sulphur application and presented in Table 3. The significantly highest total nitrogen uptake by chickpea (151.02 kg ha^{-1}) was observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found to be at par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha $^{-1}$ through Bentonite sulphur + RDF (T_5). The application of sulphur @ 10, 20 and 30 kg sulphur per ha registered increasing trend in total nitrogen uptake (123.47 to 151.02 kg ha^{-1}) in case of Bentonite sulphur and (117.60 to 142.11 kg ha^{-1}) in case of Gypsum. The application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) increased 44.39 per cent total nitrogen uptake as compared to S-free treatment.

The increase in nitrogen content in grain and straw might be due to the synergistic effect of both N and S which increased their availability in soil. The increased N uptake as results of S application might be due to an increment in protein synthesis and enhance photosynthesis [16]. Patel et al.,[12] reported that application sulphur @ 40 kg ha^{-1} increase the nitrogen content in seed and straw respectively. Srinivasulu et al. [11] reported that increasing doses of sulphur significantly increase the uptake of nitrogen, phosphorus, potassium and sulphur. These findings are in accordance with Karprekar [17], Singh et al. [18], Sindagi [19] and Kumar et al. [20].

3.3 Phosphorus Uptake

Data pertaining to phosphorous uptake is given in (Table 4). The highest total phosphorus uptake by chickpea (15.10 kg ha^{-1}) was observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found to be at par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). The phosphorus uptake by chickpea was recorded lowest in absolute control (5.76 kg ha^{-1}).The increase in phosphorous uptake with application S is might be due to Synergetic effect of sulphur application on phosphorous availability. These findings are in accordance with the results reported by Mir et al. [21], Bahadur and Tiwari [22] and Singh et al. (2016).

3.4 Potassium Uptake

Potassium uptake was also significantly improved with sulphur application. (Table 5). The significantly higher potassium uptake by chickpea (99.83 kg ha^{-1}) was observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found at par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). The lowest potassium uptake by chickpea (46.21 kg ha^{-1}) was recorded in control treatment T_1. Sulphur application might increase the availability of most of nutrient by reduction of pH of soil. This is may be reason of increased potassium uptake. The results content and uptake of potassium are in agreement with the findings reported by Singh et al. [23], Das et al. [4], Sindagi [19], Mondal et al. [24] and Solanki et al. [25].

3.5 Sulphur Uptake

The data showed in (Table 6). indicated that the significantly highest sulphur uptake by chickpea seed (20.02 kg ha^{-1}) was recorded with the application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found to be on par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9). The lowest sulphur total uptake by chickpea grain (8.35 kg ha^{-1}) was recorded in absolute control. Increase in the sulphur content in seed and straw of chickpea might be due to application of increasing doses of sulphur. Similar results were also reported by Bahadur and Tiwari [26]; Singh et al. [27,28]; Patel et al.[12]; Kumar et al. [20] and Chiaiese et al., [29] reported about the increment sulphur content in seed and stover of chickpea with the application of sulphur.. Higher nutrient coupled with higher seed and stover yield lead to higher nutrient uptake. Similar data regarding increase in the uptake of sulphur in seed and straw of chickpea with increasing doses of sulphur was reported by Kala et al. [30]; Srinivasulu et al. [11] and Islam and Ali [31]. When sulphur in bentonite-S comes into contact with soil moisture it breaks apart into fragments of fine dimension, which allows swift solubilization of S and gypsum has very low solubility. Hence availability and uptake sulphur is high with bentonite S as compared to sulphur with gypsum.

3.6 Zinc Uptake

Data pertaining to zinc uptake is given in (Table 7). Zinc Uptake was also significantly improved with application of sulphur treatment. The highest total zinc uptake (138.95 g ha^{-1}) by chickpea was observed in treatment of application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found to be at par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). The lowest total zinc uptake by chickpea crop (76.45 g ha^{-1}) was recorded in control treatment T_1. Sulphur application increased plant Zn uptake as solubility of Zn increases with decrease in soil pH. The results are corroborated with the findings reported by Sindagi [19]; Yoo and James, [32], and Cui Wang,[33].

3.7 Iron Uptake

The data regarding Iron uptake is presented in (Table 8) indicated that it is significantly improved with sulphur application. The highest total iron uptake by chickpea (313.88 g ha^{-1}) was observed with the application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) which was followed by treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). The lowest total iron uptake by chickpea crop (181.83 g ha^{-1}) was recorded in treatment absolute control. Sulphur application resulted in significant increase in Fe uptake is mainly due to acidification effect produced as result of sulphur application. The results are in accordance with the findings reported by Sindagi [19]. Sulphur application resulted in an increased in Fe uptake as a recorded by Malewar and Ismail [34].

3.8 Manganese Uptake

The data presented in (Table 9) indicated that there was significant improvement in total uptake of manganese (140.24 g ha^{-1}) by chickpea with application of treatment S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) which was followed by treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). The lowest manganese uptake by chickpea (78.42 g ha^{-1}) was recorded in control treatment T_1. There was significant increase in Mn uptake due to S application which concide with finding of Rahman et al. [35] who observed that an increase in Mn uptake by corn plant with the application elemental S as result of soil acidification although temporary. The similar findings was reported by Sindagi [19].

3.9 Copper Uptake

Data pertaining to Copper uptake is given in (Table 10). Significantly highest uptake of copper (45.48 g ha^{-1}) by chickpea was observed in treatment application of S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found to be at par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9) and S @ 20 kg ha^{-1} through Bentonite sulphur + RDF (T_5). Sulphur application resulted in a significant increase in copper uptake, which is in line with previous finding and mainly due to acidification effect produced as a result of S application. Ghosh et al., [36] and Rahman et al., [35]. The results are in accordance with the findings reported by Sindagi et al. [19].

Table 1. Grain yield of chickpea as influenced by sulphur application

	Treatments	Grain yield (Kg ha^{-1})				% Response over control	% increase over S free RDF
		2020-21	2021-22	2022-23	Pooled Mean		
1	Absolute control	1652	1380	1433	1488		
2	S free RDF (NPK through Urea, DAP, MOP)	1784	2040	1891	1905	28.0	
3	RDF (NPK through Urea, SSP, MOP)	1875	2396	2105	2126	42.8	11.58
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	1993	2356	2067	2139	43.7	12.29
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	2280	2486	2253	2340	57.2	22.82
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	2326	2558	2370	2418	62.5	26.94
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	1870	2335	2025	2076	39.5	9.01
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	1927	2445	2200	2191	47.2	15.01
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	22.00	2535	2310	2348	57.8	23.28
	SE (m) $\pm$	1.11	0.66	1.00	0.72		
	CD at 5%	3.34	1.99	3.02	2.15		
	CV	9.70	5.04	8.43	5.86		

Table 2. Straw yield of chickpea as influenced by sulphur application

	Treatments	Straw yield (Kg ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	2026	1725	1723	1825
2	S free RDF (NPK through Urea, DAP, MOP)	2197	2549	2343	2363
3	RDF (NPK through Urea, SSP, MOP)	2251	2995	2614	2620
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	2420	2938	2611	2656
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	2672	3109	2851	2877
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	2781	3198	3070	3016
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	2287	2919	2529	2579
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	2338	3058	2751	2716
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	2570	3172	2887	2876
	SE (m) $\pm$	1.11	0.86	1.21	0.94
	CD at 5%	3.33	2.57	3.64	2.82

Table 3. Total uptake of N (kg ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of N (kg ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	86.49	76.11	74.51	79.03
2	S free RDF (NPK through Urea, DAP, MOP)	96.39	115.30	102.07	104.59
3	RDF (NPK through Urea, SSP, MOP)	107.19	143.25	118.67	123.04
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	112.44	139.35	118.62	123.47
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	134.18	153.19	134.68	140.68
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	141.38	162.83	148.86	151.02
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	103.30	135.58	113.92	117.60
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	113.03	149.05	128.60	130.22
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	129.66	157.29	139.38	142.11
	SE (m) $\pm$	6.35	5.38	5.46	4.16
	CD at 5%	19.03	16.13	16.36	12.47

Table 4. Total uptake of P (kg ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of P (kg ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	6.32	6.08	4.87	5.76
2	S free RDF (NPK through Urea, DAP, MOP)	7.85	10.31	9.70	9.29
3	RDF (NPK through Urea, SSP, MOP)	9.16	13.23	12.55	11.65
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	9.45	12.51	11.86	11.27
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	11.95	14.50	14.32	13.59
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	13.38	15.50	16.41	15.10
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	8.86	11.92	10.14	10.31
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	9.38	13.73	13.28	12.13
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	12.31	14.87	15.12	14.10
	SE (m) $\pm$	0.58	0.72	1.01	0.52
	CD at 5%	1.75	2.17	3.04	1.55

Table 5. Total uptake of K (kg ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of K (kg ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	49.23	45.54	43.88	46.21
2	S free RDF (NPK through Urea, DAP, MOP)	55.40	69.48	64.28	63.05
3	RDF (NPK through Urea, SSP, MOP)	66.00	95.39	85.59	82.33
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	66.97	88.88	79.95	78.60
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	80.52	99.78	94.77	91.69
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	87.48	107.00	104.99	99.83
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	62.03	85.76	75.51	74.43
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	66.26	94.32	87.38	82.65
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	79.47	103.05	98.16	93.56
	SE (m) $\pm$	3.40	2.63	4.34	3.10
	CD at 5%	10.18	7.88	13.01	9.26

Table 6. Total uptake of S (kg ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of S (kg ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	8.65	7.83	8.57	8.35
2	S free RDF (NPK through Urea, DAP, MOP)	10.05	12.54	12.20	11.60
3	RDF (NPK through Urea, SSP, MOP)	11.79	17.08	15.29	14.72
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	11.61	15.85	15.21	14.22
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	15.65	18.73	18.37	17.59
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	17.29	20.91	21.85	20.02
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	10.70	15.29	14.04	13.34
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	12.55	17.92	17.33	15.93
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	14.99	20.11	19.39	18.17
	SE (m) $\pm$	0.86	1.00	0.99	0.62
	CD at 5%	2.59	3.00	2.99	1.85

Table 7. Total uptake of Zn (g ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of Zn (g ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	84.21	71.74	73.40	76.45
2	S free RDF (NPK through Urea, DAP, MOP)	92.86	107.84	99.68	100.12
3	RDF (NPK through Urea, SSP, MOP)	98.24	129.70	113.68	113.87
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	106.90	130.02	116.01	117.64
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	122.78	140.26	128.97	130.67
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	128.97	147.63	140.26	138.95
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	99.77	128.88	112.22	113.62
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	104.60	137.88	124.83	122.44
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	120.18	146.16	134.45	133.60
	SE (m) $\pm$	5.49	3.83	6.31	4.08
	CD at 5%	16.47	11.47	18.90	12.22

Table 8. Total uptake of Fe (g ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of Fe (g ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	200.83	172.52	172.15	181.83
2	S free RDF (NPK through Urea, DAP, MOP)	218.84	257.19	236.45	237.49
3	RDF (NPK through Urea, SSP, MOP)	229.49	305.08	265.96	266.84
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	246.74	301.92	265.86	271.51
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	280.25	321.87	293.27	298.46
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	292.56	334.05	315.02	313.88
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	232.05	299.70	258.45	263.40
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	240.23	316.36	283.70	280.10
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	272.83	330.97	300.59	301.46
	SE (m) $\pm$	13.23	10.15	14.24	9.40
	CD at 5%	39.66	30.41	42.68	28.18

Table 9. Total uptake of Mn (g ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of Mn (g ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	85.68	74.45	75.13	78.42
2	S free RDF (NPK through Urea, DAP, MOP)	93.68	111.19	101.06	101.98
3	RDF (NPK through Urea, SSP, MOP)	98.67	132.68	114.74	115.36
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	107.48	133.10	116.97	119.18
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	123.18	143.78	130.03	132.33
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	129.41	150.20	141.12	140.24
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	100.81	131.93	113.44	115.40
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	105.07	140.19	125.58	123.61
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	120.43	148.12	134.25	134.27
	SE (m) ±	5.14	5.03	6.39	4.13
	CD at 5%	15.40	15.09	19.15	12.39

Table 10. Total uptake of Cu (g ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Total uptake of Cu (g ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	21.48	18.48	19.00	19.65
2	S free RDF (NPK through Urea, DAP, MOP)	24.75	29.87	27.33	27.31
3	RDF (NPK through Urea, SSP, MOP)	27.62	37.49	33.09	32.73
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	31.56	39.93	34.79	35.43
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	38.71	45.31	41.29	41.77
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	41.93	49.01	45.49	45.48
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	29.44	39.27	33.51	34.07
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	32.44	44.14	39.01	38.53
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	38.70	48.02	43.28	43.33
	SE (m) ±	2.33	1.58	1.94	1.26
	CD at 5%	6.97	4.75	5.80	3.79

Table 11. Test weight (g/100 seeds) of chickpea as influenced by sulphur application

Treatments		Test weight (g/100 seeds)			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	19.95	20.23	21.19	20.46
2	S free RDF (NPK through Urea, DAP, MOP)	20.47	22.92	21.87	21.75
3	RDF (NPK through Urea, SSP, MOP)	21.69	24.18	23.64	23.17
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	21.20	23.69	22.15	22.35
5	T_2 + S @ 20 kg ha^{-1} through Bentonite Sulphur	21.81	24.47	23.09	23.12
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	24.55	25.67	25.10	25.11
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	20.89	23.47	22.00	22.12
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	21.33	24.08	22.81	22.74
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	24.05	25.27	24.43	24.58
	SE (m) $\pm$	0.54	0.59	0.57	0.30
	CD at 5%	1.64	1.76	1.70	0.90

Table 12. Protein content (%) of chickpea as influenced by sulphur application

Treatments		Protein content (%)			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	18.58	19.46	18.91	18.98
2	S free RDF (NPK through Urea, DAP, MOP)	19.20	19.77	19.63	19.53
3	RDF (NPK through Urea, SSP, MOP)	19.59	20.71	19.92	20.07
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	20.03	19.94	20.17	20.04
5	T_2 + S @ 20 kg ha^{-1} through Bentonite Sulphur	20.41	20.76	20.80	20.66
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	20.95	21.09	21.34	21.13
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	19.92	19.90	20.02	19.95
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	20.22	20.55	20.68	20.48
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	20.68	20.87	20.93	20.83
	SE (m) $\pm$	0.45	0.39	0.34	0.13
	CD at 5%	1.34	1.18	1.03	0.39

Table 13. Protein yield (kg ha^{-1}) of chickpea as influenced by sulphur application

Treatments		Protein yield (kg ha^{-1})			
		2020-21	**2021-22**	**2022-23**	**Pooled Mean**
1	Absolute control	306.82	268.90	270.23	282.0
2	S free RDF (NPK through Urea, DAP, MOP)	341.82	403.20	370.42	371.8
3	RDF (NPK through Urea, SSP, MOP)	367.15	496.10	420.19	427.8
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	398.78	470.00	416.30	428.4
5	T_2 + S @ 20 kg ha $^{-1}$ through Bentonite Sulphur	466.37	515.80	467.67	483.3
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	487.07	539.50	505.78	510.8
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	371.76	464.20	405.50	413.8
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	390.22	502.60	454.68	449.2
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	455.02	528.70	483.60	489.1
	SE (m) $\pm$	21.15	16.27	20.33	14.11
	CD at 5%	13.39	48.78	60.94	42.31

3.10 Quality of Chickpea

The test weight (Table 11) of chickpea seed was found to vary from 20.46 to 25.11 g. Test weight (100 seed) was found to increase with the application of increasing doses of sulphur. The significantly highest test weight in chickpea seed (25.11 g) was recorded in treatment S @ 30 kg ha^{-1} through Bentonite sulphur + RDF (T_6) and it was found to be at par with treatment S @ 30 kg ha^{-1} through Gypsum + RDF (T_9). The lowest test weight in chickpea seed (20.46) was recorded in control treatment T_1. The application of increasing dose of sulphur from 10 to 30 kg S per ha on sulphur deficient soils increased the test weight of chickpea linearly from 22.35 to 25.11 g with Bentonite sulphur and from 22.12 to 24.58 g with Gypsum, respectively.

Data pertaining to Protein Content (%) is given in (Table 12). The protein content of chickpea seed was found to vary from 18.98 to 21.13 % in all treatment. Data pertaining to protein yield (kg ha^{-1}) is given in (Table 13). The protein yield of chickpea seed was found to vary from 282.0 to 510.8 kg ha^{-1} due to application of sulphur. Data revealed that the protein content (%) and protein yield (kg ha-1) in (Table 12 and 13) were affected due to application of sulphur application might be due to increased sulphur and nitrogen availability which help in synthesizing some sulphur containing amino acids like Homocysteine, Cysteine and methionine, thus resulting in increased synthesis of protein. Similar finding were also reported by Kaisher et al.[37]; Patel *et al.* (2010) and Singh [27,28] reported that combined application of S (20 kg ha^{-1} recorded significantly higher protein content over control. Ram and Katiyar [38-40] revealed that increase in S levels from 0 to 40 kg ha^{-1} significantly increased the protein content (23.92 and 24.07%) [41-44].

4. CONCLUSION

On the basis of the above findings, it can be concluded that among the various treatments combinations, the application of S @ 30 kg ha^{-1} through Bentonite sulphur along with RDF exhibited better performance in chickpea crop there by influencing the yield, uptake and quality were significantly at T_6 .The significantly highest grain and straw yield were recorded with the application of S @ 30 kg ha^{-1} though Bentonite sulphur along with RDF and the lowest Grain and straw yield was recorded in treatment absolute control. Similarly, highest N, P, K, S and micronutrient uptake and quality parameters like test weight, protein (%) and protein yield (kg ha^{-1}) were observed with application of @ 30 kg ha^{-1} through Bentonite sulphur along with RDF followed by the treatment of application of S @ 30 kg ha^{-1} through Gypsum + RDF. These results suggest that optimizing sulphur application along with RDF fertilizer can be a promising strategy for sustainable yield and quality improvement in chickpea production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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