Original Research Article

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

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,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 incorporation~~ the application of sulphur application is significantly influenced the yield, uptake and quality. The highest seed yield (24.18 q ha^{-1}) and straw yield (30.16 q ha^{-1}) were recorded with the application of S @30 kg ha^{-1} through Bentonite sulphur along with RDF 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 RDF followed by the treatment of application of S @ 30 kg ha^{-1} through Gypsum + RDF.

Key words: Bentonite Sulphur, Gypsum, Yield, Uptake, Quality, Chickpea.

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Ex:Quintals per hectare (q ha^{-1})
Ex: Kilograms per hectare (kg ha-1)
Ex: RDF???

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) (Anonymous, 2017 (b)). India ranks first in Chickpea production. The largest gram producing state in India with respect to area are Madhya Pradesh, Maharashtra Uttar Pradesh, Andhra Pradesh, Rajasthan, Haryana and Karnataka. Madhya Pradesh rank first in Chickpea production. Maharashtra second major Chickpea producing state after Madhya Pradesh. In Maharashtra area under Chickpea crop was 13.53 lakh hectares with the production of 11.80 lakh tonnes with an average productivity of 872 kg ha^{-1}. Therefore, Maharashtra contributes 18.36 per cent share in area and 20.03 per cent share in production of chickpea in India.

Sulphur is the 4th major essential plant nutrient after N, P and K ~~because of~~due to its role in the synthesis of proteins, vitamins, enzyme and flavoured compounds in plant. Its amount required by the plant is ~~even higher than~~similar to phosphorus ~~and comes after~~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 have been reported from over 70 countries worldwide including India. Soil sulphur deficiency is ~~becoming deficient in soil~~increasing due to the use of high-grade S -free fertilizers, cultivation of high- yielding varieties and lack of industrial activity (Scherer, 2009).

The **The rapid depletion of sulphur in** ~~sulphur status of~~ Indian ~~as well as~~and Maharashtra soil ~~is~~ pose a significant challenge to agriculture productivity.~~changing rapidly because of heavy removal of the nutrients from the soil under multiple cropping system with~~this depletion is primarily driven by intensive multiple cropping systemsthat 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 (Das *et al.,* 2016).

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 % (Shukla *et al*., 2016), while in Maharashtra sulphur deficiency recorded to the extent of 37.48 % while in Vidarbha it was noticed 25.76 % (Katkar *et al*., 2017). ~~So~~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 ~~study the "Effect of sulphur application on yield, uptake and quality of chickpea (*Cicer arietinum* L.)~~.

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2. MATERIALS AND METHODS

The experiment was conducted to study the sulphur requirement of Chickpea crop. The soil was analysed for soil properties, plant and seed samples were analysed for nutrient uptake and quality of chickpea crop.

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The field experiment was conducted at Pulse Research Unit, Dr.Panjabrao Deshmukh Krishi Vidyapeeth, Akola during rabi season 2020-21 to 2022-23. 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 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, Fe, Cu and Mn (mg kg^{-1}). Treatment details were as T_1

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was Absolute Control, T_2 is S-free RDF (N, P_2O_5, K_2O through Urea, DAP, MOP), T_3 was RDF (N, P_2O_5, K_2O through Urea, SSP, MOP), 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 plant samples were also collected at maturity stage. The samples 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 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 (Chapman pratt 1962), potassium by using Flame Photometer (Hanway and Heidal 1952), sulphur was estimated from di-acid extract turbidimetrically using Spectrophotometer (Chesnin and Yien 1950) and micro nutrients by using AAS (Issac and Kerber 1971). The test of statistically significance of the experimental data was carried out as per procedure described by (Panse and Sukhatme 1985).

3. RESULTS AND DISCUSSION

Yield of Chickpea: The data pertaining to seed yield of chickpea was influenced significantly (Table 1). The significantly higher seed yield (24.18 q 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 seed yield of chickpea (14.88 q ha^{-1}) was recorded in absolute control. Our results are in line with Srinivasulu *et al.* (2015),reported the effect of sulphur application in increasing the seed and straw yield of chickpea, while Das *et al*. (2016), 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 cystein, methionine and chlorophyll synthesis. Thus, these ~~bioactivity~~ bioactivitiesof sulphur might have played important role in improving yield attributing characters and yield of chickpea. Similar results were also given by Patel *et al.* (2014).

Data in (Table 2). The significantly higher straw yield (30.16 q 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 (18.25 q ha^{-1}) was recorded in control treatment T_1. Jadeja *et al*. (2016), also reported increased seed and straw yield of chickpea with sulphur application as compared to control.

The increase in seed and straw yield was might be due to increased sulphur availability and uptake as well as it's active involvement in synthesis of amino acids, regulation of various metabolic and enzymatic processes along with enhanced nitrogen fixation and biomass accumulation which

Comment [N5]: For the first time clarify RDF (recommended dose of fertilizers)

Comment [N6]: Explain the abbreviations like DAP, MOP, SSP at first appearance

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Comment [N8]: Mention the number of plantes

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Ex: These increases likely stem from enhanced sulfur availability and uptake

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ultimately contributed to growth and yield. Similar finding of increased stover yield with sulphur application were also given by Srinivasulu *et al.* (2015).

Nutrient Uptake:

Nitrogen Uptake: Data pertaining to Nitrogen uptake is given in (Table 3).There is significant improvement of nitrogen uptake with inoculation of sulphur treatment 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.

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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 (Yanwen Zhao *et al.,*2013). Patel *et al*., (2014) reported that application sulphur @ 40 kg ha^{-1} increase the nitrogen content in seed and straw respectively. Srinivasulu *et al*. (2015) reported that increasing doses of sulphur significantly increase the uptake of nitrogen, phosphorus, potassium and sulphur. These findings are in accordance with Karprekar (2003), Singh *et al*. (2004), Sindagi (2014) and Kumar *et al*. (2006).

Phosphorus Uptake: Data pertaining to phosphorous uptake is given in (Table 4). ~~Significantly~~ The ~~higher~~ highesttotal 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 chickpeawas 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*. (2013), Bahadur and Tiwari (2014) and Singh *et al.* (2016). Better root growth with proper nutrient supply may be the reason for extraction of available plant nutrient from soil depth and ultimately which improve the nutrient content in plant parts.

Potassium Uptake: Potassium uptake was also significantly improved with inoculation of sulphur treatment and presented in (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

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content and uptake of potassium are in agreement with the findings reported by Singh *et al.* (2013), Das *et al*. (2016), Sindagi (2014), Mondal *et al*. (2005) and Solanki *et al*. (2017).

Sulphur Uptake: The data showed in (Table 6). indicated thatthe 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 (2014); Singh *et al*. (2008); Patel *et al*. (2014); Kumar *et al*. (2006) and Chiaiese *et al*., (2004) reported about the increment sulphur content in seed and stover of chickpea with the application of sulphur. Application of sulphur resulted in increased nitrogen fixation which ~~might have~~ potentially promoted ~~production of higher amount~~ boosting of above grounds dry matter that could have led to higher acquisition of nutrients ultimately resulted in higher nutrient content in seed and stover. 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*. (2017); Srinivasulu *et al*. (2015) and Islam and Ali (2009). 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.

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 (2014); Yoo and James, (2003), and Cui Wang, (2005),

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 ~~increased~~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 (2014). Sulphur application resulted in an increased in Fe uptake as a recorded by Malewar and Ismail (1997).

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

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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.* (2011) 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 (2014).

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*., (2000) and Rahman *et al*., (2011). The results are in accordance with the findings reported by Sindagi *et al.* (2014).

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 findings were also reported by Kaisher *et al.* (2010); Patel *et al.* (2010) and Singh (2008) reported that combined application of S (20 kg ha^{-1} recorded significantly higher protein content over control. Ram and Katiyar (2013) revealed that increase in S levels from 0 to 40 kg ha^{-1} significantly increased the protein content (23.92 and 24.07%).

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Table 1: Seed yield of chickpea as influenced by sulphur application

	Treatments	Seedyield(q ha^{-1})				% Response over control	% increase over S free RDF
		2020-21	2021-22	2022-23	Pooled Mean		
1	Absolute control	16.52	13.80	14.33	14.88		
2	S free RDF (NPK through Urea, DAP, MOP)	17.84	20.40	18.91	19.05	28.0	
3	RDF (NPK through Urea, SSP, MOP)	18.75	23.96	21.05	21.26	42.8	11.58
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	19.93	23.56	20.67	21.39	43.7	12.29
5	T_2 + S @ 20 kg ha^{-1} through Bentonite Sulphur	22.80	24.86	22.53	23.40	57.2	22.82
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	23.26	25.58	23.70	24.18	62.5	26.94
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	18.70	23.35	20.25	20.76	39.5	9.01
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	19.27	24.45	22.00	21.91	47.2	15.01
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	22.00	25.35	23.10	23.48	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 (q ha^{-1})			
		2020-21	2021-22	2022-23	Pooled Mean
1	Absolute control	20.26	17.25	17.23	18.25
2	S free RDF (NPK through Urea, DAP, MOP)	21.97	25.49	23.43	23.63
3	RDF (NPK through Urea, SSP, MOP)	22.51	29.95	26.14	26.20
4	T_2 + S @ 10 kg ha^{-1} through Bentonite Sulphur	24.20	29.38	26.11	26.56
5	T_2 + S @ 20 kg ha^{-1} through Bentonite Sulphur	26.72	31.09	28.51	28.77
6	T_2 + S @ 30 kg ha^{-1} through Bentonite Sulphur	27.81	31.98	30.70	30.16
7	T_2 + S @ 10 kg ha^{-1} through Gypsum	22.87	29.19	25.29	25.79
8	T_2 + S @ 20 kg ha^{-1} through Gypsum	23.38	30.58	27.51	27.16
9	T_2 + S @ 30 kg ha^{-1} through Gypsum	25.70	31.72	28.87	28.76
	SE (m) $\pm$	1.11	0.86	1.21	0.94
	CD at 5%	3.33	2.57	3.64	2.82

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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

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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) ±	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) ±	0.86	1.00	0.99	0.62
	CD at 5%	2.59	3.00	2.99	1.85

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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) ±	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) ±	13.23	10.15	14.24	9.40
	CD at 5%	39.66	30.41	42.68	28.18

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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) $\pm$	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) $\pm$	2.33	1.58	1.94	1.26
	CD at 5%	6.97	4.75	5.80	3.79

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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

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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

4. CONCLUSION

On the basis of the above findings, it ~~may~~ canbe 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 thereby influencing the yield, uptake and quality were significantly at T_6 .The significantly highest grain yield (24.18 q ha^{-1}) and straw yield (30.16 q ha^{-1}) were recorded with the application of S @ 30 kg ha^{-1} though Bentonite sulphur along with RDF and the lowest seed yield (14.88 q ha^{-1}) and straw yield (18.25 q ha^{-1}) 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 sulfur application along with RDF fertilizer can be a promising strategy for sustainable yield and quality improvement in chickpea production.

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Comment [N13]: It would be beneficial to update the reference list with more recent publications

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