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Effect of $ZnSO_4$ on yield and quality of Gobhi Sarson (*Brassica napus*) var GSC-7

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Abstract: The present investigation was conducted to assess the effect of soil and foliar application of $ZnSO_4$ on Gobhi Sarson var GSC-7. The experiment was conducted for two consecutive rabi seasons of 2022-23 and 2023-24 at Bhagot farm of KVK Chamba (Himachal Pradesh), Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, to study the effect of $ZnSO_4$ on growth, yield, uptake of nutrients and quality of seeds in Gobhi sarson. There were six treatments viz. T_1: RDF + soil application of $ZnSO_4$ @ 25kg/ha, T_2: RDF + foliar application of $ZnSO_4$ @ 5g/litre at 45 days after sowing, T_3: RDF + foliar application of $ZnSO_4$ @ 5g/litre at 45 and 60 days after sowing, T_4: RDF + foliar application of $ZnSO_4$ @ 5g/litre at 45 and 75 days after sowing T_5: RDF, and T_6: Farmer's practice i.e. application of FYM only. The experiment was laid out in randomized complete block design in replication of three. The results indicated that soil application of RDF + $ZnSO_4$ @ 25 kg/ha was most effective which was followed by RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS in reducing the number of days for flower initiation (88.71 and 88.20), increased branches bearing pods (15.54 and 14.93), plant height (190.33 and 188.33), number of siliquae/plant (215.67 and 214.30), 1000 seed weight (4.34 g and 4.29 g), seed yield/plant (6.33 g and 6.27 g), oil yield (337.42 kg/ha and 334.58 kg/ha), protein yield (357 kg/ha and 353.67 kg/ha), germination % (93.33 and 92.67) and other seed quality parameters. The soil application of $ZnSO_4$ at 25 kg/ha or foliar application @ 5g/litre at 45 and 60 days after sowing were effective treatments in enhancing growth, yield, uptake, status of nutrients and quality of produce in Gobhi sarson in present investigation.

Key words: Gobhi sarson • $ZnSO_4$ • Growth • Yield • Seed quality

Introduction

Gobhi sarson (*Brassica napus*) is one of the most important oilseed crop cultivated all over the world. Oilseed crops play an important role in human and animal nutrition for maintaining the normal health. India occupies the highest area and leads in production of rapeseed and mustard crops (Chauhan et al 2020). Total area under rapeseed and mustard in India is 5.98 million hectares with a production of 8.32 million tonnes and productivity of 1397 kg ha^{-1} (Anonymous 2019). The daily requirement of oil has been estimated to be 55 g of edible oil or 110 g seed (assuming 50% extractability) for human diet (Mukherjee 2010). It is predominantly cultivated in the states of Rajasthan, Uttar Pradesh, Haryana, Himachal Pradesh, Madhya Pradesh, Gujarat and some non-traditional areas of South India.

Nutrient management is one of the most important agronomic factors that affects the yield of all the crops. The decline in mustard crop yield is closely associated with the deterioration of soil quality, namely the depletion of nutrients. This can be due to either inadequate use of fertilizers or imbalanced fertilization practices (Roy et al 2013; Haque et al 2014; Rabbani et al 2023). The farmers, by and large use mainly nitrogen and phosphorus as a nutrients in mustard cultivation and as a consequences, deficiencies of Zn and other micro-nutrients are increasing (Shukla 2011). Zinc is one of the essential plant micronutrient and its importance for crop productivity is similar to that of major nutrients. The impact of fertilizers on crop yield and its associated attributes, as well as the importance of rationalizing fertilizer usage and resource management to sustain crop productivity, have been emphasized in previous studies (Sultana et al 2015; Sultana et al 2019). The growth of plants can be restricted if any of the micronutrients in the soil are absent, even if all other nutrients are available in sufficient quantities. Gobhi sarson also has the capacity to deplete micronutrients from the soil, and these nutrients cannot be restored solely through the application of NPK fertilizers. The application of micronutrients is necessary in order to attain a state of balanced nutrition. Zinc (Zn) is a crucial component of numerous enzymes that play a regulatory role in diverse metabolic processes within plants. Additionally, it exerts an influence on the synthesis of various growth hormones, such as indole-3-acetic acid (IAA), in plants. Zn has been found to have a stimulating effect on pod development, seed formation, and oil synthesis in mustard seeds (Halim et al., 2023). Additionally, it has been observed to enhance the overall yield of mustard in terms of both seed and stover production (Sinha et al 2000; Sultana et al 2020).

Zinc has specific and essential physiological functions in plant metabolism. At least four enzymes contain zinc: carbon anhydrase, alcohol dehydrogenase, super oxide dismutase and RNA polymerase, which are involved in photosynthetic CO_2 fixation, anaerobic root respiration, detoxification of super oxide radicals and protection of membrane, lipids and proteins against oxidation. Zinc is important in protein and growth regulators synthesis. Deo and Khandelwal (2009) reported that application of 5 kg Zn/ha significantly increased the seed and stover yield by 14 and 4.9% over control. Zinc deficiency is wide spread throughout the country. Nearly 50% of cultivated soils in India are low in plant available zinc and these soils are under intensive cultivation with no or little application of zinc fertilizers. As low soil Zn status is an important limiting factor responsible for poor yields of the crops, it is imperative to evaluate the response of Zn nutrition on mustard productivity. Zinc deficiency is most commonly corrected by application of zinc sulphate as of its high solubility and low cost. The present investigation aimed to study the effect of soil and foliar application at different time periods of $ZnSO_4$ on yield and seed quality parameters in Gobhi sarson.

Material and methods

The field experiment was conducted during the rabi seasons of 2022-23 and 2023-24 in the mid hills of Chamba district of Himachal Pradesh at Bhagot farm of Krishi Vigyan Kendra Chamba with coordinates, 32°33’41’’ N latitude and 76°07’12’’ E longitude and at an altitude of 859 m above mean sea level. The experimental site is characterized as sub mountain low hills with sub tropical climate lying in zone II of Himachal Pradesh. The agro climatic data of the trial location is given in Table 1.

The soil of the experimental area was sandy loam having a ph of 6.8, available N 410 kg/ha, available P 37 kg/ha, available K 210 kg/ha, available Zn 1.25 mg/kg, available S 16 kg/ha. The healthy seeds of Gobhi sarson var. GSC-7 was procured from the department of Seed Science and Technology, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishwavidyalaya, Palampur, Kangra, Himachal Pradesh. Zinc Sulphate was procured from CDH industries New Delhi, India.

Table 1: Agro climatic data of cropping season during 2022-23 and 2023-24.

2022-23	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)		2023-24	Rainfall (mm)	Min Temp (°C)	Max Temp (°C)
Sep-22	82	14.9	33.4		Sep-23	70	16.3	30.9
Oct-22	76.5	9.5	32.6		Oct-23	43.5	9.3	29.8
Nov-22	65	5.1	29.1		Nov-23	15.5	6.7	28.2
Dec-22	16	1.9	24.8		Dec-23	1	2.2	24.4
Jan-23	199	1.4	22.7		Jan-24	38	2.06	22.3
Feb-23	25	3.1	29.6		Feb-24	143.5	2.4	23.2
Mar-23	85	8.6	27.9		Mar-24	196.5	5.7	30.1
Apr-23	153	8	29.5		Apr-24	178	10.4	33.9
May-23	167.5	11.2	38.5		May-24	0.5	10.7	34.4

The field was prepared by thorough ploughing followed by planking and then the plots were prepared having the dimensions of 3 m × 1.5 m. The experimental area was divided into three blocks and each block was allocated one replication each. The treatment details are as follows: T_1: RDF + soil application of $ZnSO_4$ @ 25kg/ha, T_2: RDF + foliar application of $ZnSO_4$ @ 5g/litre at 45 days after sowing, T_3: RDF + foliar application of $ZnSO_4$ @ 5g/litre at 45 and 60 days after sowing, T_4: RDF + foliar application of $ZnSO_4$ @ 5g/litre at 45 and 75 days after sowing, T_5: RDF and T_6: Farmer's practice i.e. application of FYM only. RDF included the application of N as calcium ammonium nitrate @ 240 kg/ha, phosphorus as single super phosphate @ 250 kg/ha and potassium as muriate of potash @ 65 kg/ha. Half of the N and complete quantity of P and K was applied as basal dose at the time of field preparation while the remaining half of N was applied before flowering i.e. 85 days after sowing. The design used was randomized complete block design and each treatment was replicated thrice.

Growth related parameters were recorded during the crop growth while the yield and seed quality parameters were observed after the harvest. For days to flower initiation, days were counted until half of the plants in the plots started to flower. Plant height was measured using measuring tape and the average of 10 plants was taken into consideration. Number of pods bearing branches from ten plants per plot was counted and means value of ten plants was taken. For number of silique per plant, silique from ten plants per plot was counted and means value of ten plants was recorded. For number of seeds per siliqua, 10 pods were randomly selected from ten plants and number of seeds per silique was counted and average was worked out. For test weight, five samples of one thousand seeds were taken and their average was taken for calculating the test weight. Seed yield per plant: seed yield from ten randomly selected plants was averaged for calculating seed yield per plant. Seed yield per hectare was calculated using the following formula:

$$\text{Seed yield per ha (kg)} = \frac{\text{Seed yield per plot (g)} \times 10{,}000 \times 0.80}{\text{Size of the plot (m}^2\text{)} \times 1000}$$

Stover yield was calculated by weighing stover of ten randomly selected plants and their average was worked out for stover yield.

Protein content (%) in seed, nitrogen content was estimated by modified Kjeldahl method and protein content was calculated by multiplying it with a factor of 6.25. Protein yield was calculated from protein content and seed yield. Oil content in the whole seed of mustard was determined by employing non-destructive method of oil estimation using nuclear magnetic resonance, spectroscope. Oil yield per hectare was figured out by oil outcome by extracting oil from the seeds.

Seed quality parameters were tested using the procedures given by ISTA (International Seed Testing Association). As per ISTA procedure germination test was conducted with one hundred seeds from each treatment per replication. The paper towel method as described earlier was used for observing germination percentage. The first count was taken on the 10th and the final count on the 14th day of the test. The germination percentage was worked out using the following formula:

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds used}} \times 100$$

For recording the seedling length ten seedlings were selected randomly from each treatment after 14 days and the length were measured with the help of a scale. Mean values calculated from ten seedlings were expressed as seedling length (cm). For recording the seedling length ten seedlings were selected randomly from each treatment after 14 days and then placed in the oven at 60ºC for 48 hours. After 48 hours, the dry weight of the seedlings was measured with a digital weighing balance. Mean values calculated from ten seedlings were expressed as seedling dry weight (mg). For the calculation of SVI-I (Seed vigour index I), the formula given by Abdul-Baki and Anderson (1973) was used:

Seed vigour index-I = Germination (%) x Seedling length (cm)

SVI-II (Seed vigour index-II): For the calculation of Seed vigour index II, the formula given by Abdul-Baki and Anderson (1973) was used:

Seed vigour index-II = Germination (%) x Seedling dry weight (mg).

Seedling emergence: The seedling emergence (%) was determined by counting the total number of seedlings when the emergence was completed or when there was no further addition in the total emergence i.e. on 14^{th} day. The number of seedlings emerged were counted on each day from 1^{st} day to 14^{th} day and the speed of emergence was calculated as described by Maguire (1962).

No. of seedlings emerged/1(1^{st} day of sowing) +……+ no. of seedlings emerged on last day/day of last count (14^{th} day of sowing)

Nutrient uptake: Plant samples were collected, first air dried, then in oven for 2 days at 60^0C till constant weight is observed. The dried samples were then powdered and stored for further analysis. The quantity of sample taken for analysis was 1 g. For nitrogen content powdered samples were digested with concentrated H_2SO_4 using digestion mixture and total nitrogen was determined by micro kjeldahl's method (Jackson 1967a). For Phosphorus content, samples were digested with diacid mixture of HNO_3 and $HClO_4$ in the ratio of 9:4 and the extract was made to a definite volume. Total phosphorus was determined by Vanadomolybdate phosphoric acid yellow colour method at 470 nm (Jackson, 1967b). Potassium content was determined by using flame photometer from the extract obtained by digestion with di-acid mixture (Chapman and Brown, 1950). Sulphur content was determined turbiditimetrically (Chesnin and Yien 1951). Zinc content was analyzed spectrophotometrically (Jackson 1973) using atomic absorption spectrophotometer. The concentration of nitrogen, phosphorus potassium, sulphur and zinc content were determined in plant samples and uptake was calculated as follows:

Uptake (kg/ha) = [% concentration of nutrient x yield of crop in q/ha (on oven dry weight basis)].

Post harvest soil parameters: Organic carbon was determined by Walkley and Black's rapid titration method (Piper 1966). Available N was determined by Alkaline Permanganate method (Subbiah and Asija 1956). Available P was determined by 0.5M NaHCO3, pH 8.5 (Olsen et al. 1954). Available K was determined by Ammonium acetate (pH 7.0) method (Black 1965). Available S was determined after extraction with 0.15% CaCl2 solution (Chesnin and Yien 1951). Available Zn was determined by Lindsay and Norvell (1978).

The data thus obtained were analyzed statistically using analysis of variance technique for various parameters at 5% level of significance. Statistical analysis was done by using the statistical software SPSS version 16 (SPSS Inc., Chicago, IL, USA) and Microsoft Excel (Microsoft, Redmond, WA, USA) at p=0.05 level of significance.

Results and Discussion:

The results in the table 2, indicates that the application of $ZnSO_4$ significantly affected days to flower initiation. All the treatments affected flowering however the application of RDF + $ZnSO_4$ 25 kg/ha was most effective which was followed by RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS in reducing the number of days for flower initiation and values of both the treatments were statistically at par with each other. The maximum days for flowering were observed in farmer's practice during both the years (Table 2). This reduction in flowering time might be attributed to properties of Zn as a micro nutrient where Zn helps the plants to store more reserves of carbohydrates through photosynthesis. Thus, higher accumulation of carbohydrates in plant leads early flower bud initiation and early flowering. The results are supported by the findings of Vanlalruati et al (2019) in which application of $ZnSO_4$ @ 0.5% resulted in early flowering in chrysanthemum.

Table 2: Effect of Zn application on days to flower initiation and number of branches bearing pods

	Days to flower initiation		No. of branches bearing pods	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	88.71 ± 0.87	88.20 ± 0.60	15.54 ± 0.32	14.93 ± 0.28
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	91.17 ± 0.69	89.40 ± 0.63	14.24 ± 0.16	14.36 ± 0.29
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	89.20 ± 0.62	89.14 ± 0.32	14.66 ± 0.22	14.58 ± 0.18
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	90.66 ± 0.35	89.57 ± 0.55	13.88 ± 0.24	13.44 ± 0.30
RDF (Control)	92.05 ± 0.35	90.25 ± 0.07	13.38 ± 0.29	12.78 ± 0.25
Farmer Practice	93.30 ± 0.60	91.96 ± 0.32	11.63 ± 0.53	11.70 ± 0.46
C.D. $_{0.05}$	1.687	1.31	0.95	1.06

Concerning number of branches bearing pods (Table 2), plant height and number of siliquae/plant (Table 3), basal application of RDF + $ZnSO_4$ 25 kg/ha was most effective in enhancing all of these which was followed by the treatment RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS. The treatment RDF + $ZnSO_4$ 25 kg/ha enhanced plant height by 11% during both the years while number of branches bearing pods by 33 % and 27 % and number of and siliquae/plant by 17 % and 15 % during 2022-23 and 2023-24 respectively. It was also observed that there was no statistical difference between basal application of RDF + $ZnSO_4$ 25 kg/ha and RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS. This increase in plant height, no. of branches bearing pods and number of siliquae/plant and might be ascribed to increased physiological activity and elongation of cell. $ZnSO_4$ application might have enhanced auxin synthesis, proteins and biosynthesis of photo assimilates which enhanced the height, no. of branches and number of siliquae/plant in mustard plants. In addition to that, Zn is known to improve root system of the plants which helps in nutrient absorption and utilization. Further, as per Vanlalruati et al. (2019) Zn affect various enzymes such as peroxidase, catalase, alcohol, dehydrogenase, tryptophan synthates etc which are responsible for synthesis of chlorophyll and activation of many physiological activities which in turn enhanced plant growth and development, these mechanisms might have played an important role in increasing all these parameters. The findings are supported by the results of Vanlalruati et al. (2019) in chrysanthemum, Kakade et al (2009) and Kumar and Haripriya (2010) in nerium.

Table 3: Effect of Zn application on plant Height and number of siliquae/ plant

	Plant Height		No. of siliquae/ plant	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	190.33 ± 1.76	188.33 ± 0.67	215.67 ± 1.31	214.30 ± 2.67
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	185.67 ± 0.88	183.33 ± 0.67	205.57 ± 2.28	202.97 ± 2.51
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	187.33 ± 0.34	184.33 ± 0.88	203.10 ± 2.76	206.00 ± 2.23
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	183.67 ± 1.45	182.67 ± 0.88	202.87 ± 4.46	199.73 ± 2.22
RDF (Control)	179.33 ± 0.88	178.67 ± 0.88	195.50 ± 1.25	194.20 ± 1.63
Farmer Practice	170.67 ± 0.88	169.33 ± 1.33	183.33 ± 1.85	186.20 ± 2.26
C.D. $_{0.05}$	3.72	2.69	8.93	6.86

As it can be observed from Table 4 that application of $ZnSO_4$ had no significant effect on number of seeds per siliqua however there was a significant difference between different treatments regarding 1000 seed weight. Highest 1000 seed weight was observed from the treatment RDF + $ZnSO_4$ 25 kg/ha which was followed by RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS and the lowest value was observed in farmer's practice. Application of RDF + $ZnSO_4$ 25 kg/ha increased 1000 seed weight by around 7 % as compared to farmers practice.

Table 4: Effect of Zn application on number of seeds/siliquae and 1000 seed weight

	No. of seeds/siliquae		1000 seed weight (g)	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	13.90 ± 0.12	13.77 ± 0.32	4.34 ± 0.04	4.29 ±0.04
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	14.03 ± 0.13	13.97 ± 0.18	4.18 ± 0.06	4.20 ±0.01
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	13.27 ± 0.12	13.73 ± 0.29	4.21 ± 0.06	4.25 ±0.03
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	13.80 ± 0.27	13.87 ± 0.12	4.11 ± 0.03	4.12 ±0.03
RDF (Control)	13.63 ± 0.29	14.10 ± 0.17	4.08 ± 0.03	4.02 ±0.00
Farmer Practice	13.77 ± 0.24	13.70 ± 0.32	4.05 ± 0.02	3.99 ±0.02
C.D. $_{0.05}$	N/A	N/A	0.14	0.08

As can be seen in the table 5, application of $ZnSO_4$ significantly affected both seed as well as stover yield. Application of RDF + $ZnSO_4$ 25 kg/ha increased the seed yield by almost 10 % and 8 % in 2022-23 and 2023-24 respectively, while application of RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS enhanced the seed yield by around 6 % during both years. The trend was similar in case of stover yield and treatments with application of RDF + $ZnSO_4$ 25 kg/ha recorded highest value for stover yield. There was about 30 % increase in stover yield as compared to control after the application of RDF + $ZnSO_4$ 25 kg/ha. Both the treatments i.e.

RDF + $ZnSO_4$ 25 kg/ha and RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS were statistically at par with each other in case of seed and stover yield. The lowest value of seed and stover yield was observed from farmer's practice. The increase in 1000 seed weight might be attributed to increased accumulation of assimilates in the sink i.e. seed. As described earlier, Zn when available to plants in adequate amount results in increased synthesis of chlorophyll content, enzyme activation and better root system which helps the plant to accumulate more assimilates in seed and plants. These mechanisms might have played an important role in increasing 1000 seed weight, seed and stover yield in the present investigation. Similar results were obtained by Usman et al 2014 in green gram, Rathi et al (2009) in black gram after the application of optimum doses of $ZnSO_4$.

Table 5: Effect of Zn application on seed yield and stover yield

	Seed yield/plant		Stover yield	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	6.33 ± 0.08	6.27 ± 0.13	18.98 ± 0.47	19.47 ± 0.61
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	6.11 ± 0.05	6.11 ± 0.04	18.07 ± 0.31	17.38 ± 0.41
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	6.13 ± 0.06	6.18 ± 0.02	17.19 ± 0.32	18.59 ± 0.38
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	5.97 ± 0.06	6.02 ± 0.05	15.72 ± 0.56	15.85 ± 0.23
RDF (Control)	5.91 ± 0.06	5.98 ± 0.07	15.09 ± 0.43	15.42 ± 0.40
Farmer Practice	5.74 ± 0.06	5.80 ± 0.07	14.55 ± 0.34	14.84 ± 0.30
C.D. $_{0.05}$	0.21	0.24	1.32	1.06

As visible from table 6, germination % of harvested seed was altered by the application of $ZnSO_4$ and highest germination % of 93 % (2022-23) and 92 % (2023-24) was observed from the application of RDF + $ZnSO_4$ 25 kg/ha which was followed by application of RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS and the 91 % and 92 % germination % was recorded. These two treatments were statistically at par with each other.

Table 6: Effect of Zn application on germination % of harvested seeds

	Germination %	
Treatment	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	93.33 ± 0.33	92.67 ± 0.88
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	89.33 ± 1.20	88.33 ± 0.33
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	91.33 ± 1.20	90.33 ± 0.88
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	91.67 ± 0.33	92.00 ± 1.00
RDF (Control)	88.67 ± 0.88	87.67 ± 0.67
Farmer Practice	87.33 ± 1.20	86.33 ± 0.88
C.D. $_{0.05}$	2.94	2.51

Seed quality attributes were also significantly affected by the application of $ZnSO_4$ and it is visible from the data depicted in the table 7 and 8 that RDF + $ZnSO_4$ 25 kg/ha was most effective in enhancing the seed quality and an increase of 23 % and 27 % in seedling length, 7% and 6 % seedling dry weight, 31 % and 37 % SVI I and 14 % and 13 % SVI II as compared to farmer's practice. RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS was also similarly effective and the values for seedling length, seedling dry weight, SVI I and SVI II were statistically at par with RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS.

Table 7: Effect of Zn application on seedling length and SVI I

	Seedling Length		SVI I	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	10.47 ± 0.49	10.83 ± 0.26	976.60 ± 42.87	1,003.77 ±23.61
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	9.07 ± 0.26	9.03 ± 0.24	810.43 ± 32.07	798.10 ± 24.24
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	9.93 ± 0.27	9.27 ± 0.27	907.20 ±27.19	837.57 ± 32.95
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	10.10 ± 0.21	9.17 ± 0.41	925.97 ±22.28	842.57 ± 29.56
RDF (Control)	8.90 ± 0.17	8.83 ± 0.35	789.43 ±23.07	774.77 ± 35.57
Farmer Practice	8.50 ± 0.21	8.47 ± 0.15	742.33 ±20.94	731.20 ± 19.80
C.D. $_{0.05}$	0.90	0.91	97.43	87.76

Table 8: Effect of Zn application on seedling dry weight and SVI II

	Seedling dry weight		SVI II	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	15.37 ± 0.27	15.26 ± 0.04	1,434.47 ±24.19	1,413.76 ±12.48
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	14.85 ± 0.12	14.77 ± 0.07	1,326.34 ±9.64	1,304.40 ±9.00
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	15.05 ± 0.11	15.11 ± 0.22	1,374.82 ±27.86	1,364.78 ±27.80
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	15.22 ± 0.09	15.19 ± 0.10	1,394.87 ±10.15	1,397.61 ±8.57
RDF (Control)	14.72 ± 0.15	14.65 ± 0.08	1,305.13 ±25.83	1,284.31 ±11.53
Farmer Practice	14.34 ± 0.23	14.40 ± 0.26	1,252.35 ±32.54	1,243.65 ±35.27
C.D. $_{0.05}$	0.59	0.48	72.88	63.08

A similar trend was observed in seedling emergence and speed of emergence (Table 9) where highest seeding emergence of 84 % (2022-23) and 85 % (2023-24) and maximum speed of emergence of 8.77 (2022-23) and 8.63 (2023-24) was observed from RDF + $ZnSO_4$ 25 kg/ha which was followed by RDF + $ZnSO_4$ spray @ 5g/L 45 and 60 DAS. The lowest values of seedling emergence and speed of emergence was recorded from farmer's practice.

Table 9: Effect of Zn application on seedling emergence and speed of emergence

	Seedling emergence		Speed of emergence	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	84.33 ±1.45	85.33 ±0.67	8.77 ±0.22	8.63 ±0.30
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	73.33 ±1.45	74.33 ±0.67	7.33 ±0.15	7.27 ±0.09
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	77.33 ±1.67	78.33 ±0.88	7.53 ±0.18	7.47 ±0.18
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	79.33 ±1.45	80.00 ±1.53	7.80 ±0.21	7.70 ±0.06
RDF (Control)	70.33 ±0.88	71.67 ±0.88	7.17 ±0.19	7.23 ±0.18
Farmer Practice	68.67 ± 0.67	70.67 ±1.76	6.97 ±0.22	6.83 ±0.20
C.D. $_{0.05}$	4.09	3.57	0.60	0.57

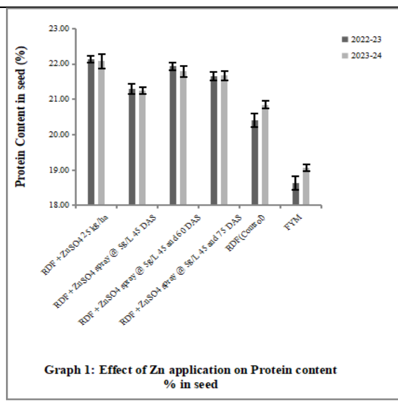
These seed quality attributes were improved by the application of $ZnSO_4$ @ 25 kg/ha. This might be because of the better quality seeds produced from the plants supplied with optimum dose of $ZnSO_4$. As discussed earlier that $ZnSO_4$ application increased 1000 seed weight by increasing the assimilated in the seeds. Thus, higher quantity of assimilates results in higher germination % and enhanced all the seed quality parameters. The results are in agreement with

Rohiwala and Bharat (2021) who also observed that 1000 seed weight increased the seed quality parameters in radish.

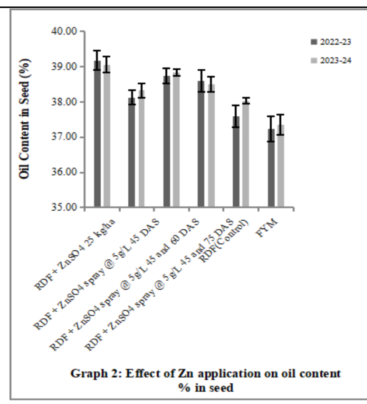
Protein in seed, protein yield, oil content and oil yield (Table 10; Figs 1, 2) was also altered by the application of RDF + $ZnSO_4$ 25 kg/ha. The similar trend as in the case of plant growth and seed quality attributes was observed and highest values for protein content, protein yield, oil content and oil yield was recorded from RDF + $ZnSO_4$ 25 kg/ha. An increase of 18 % and 15 % in protein content, 26 % and 20 % in protein yield, 5.25 % and 4.54 % in oil content and 10 % and 8% in oil yield was observed after the application of RDF + $ZnSO_4$ 25 kg/ha as compared to farmer's practice. The least values for these parameters were observed from farmer's practice.

Table 10: Effect of Zn application on protein yield/ha and oil yield/ha

	Protein yield kg/ha		Oil yield kg/ha	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	357.00 ±7.55	353.67 ±14.71	337.42 ±4.47	334.58 ± 6.72
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	329.33 ±9.35	318.00 ±10.69	318.58 ±2.99	321.24 ± 2.80
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	330.00 ±7.77	340.00 ±7.55	326.93 ±3.39	325.87 ± 2.16
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	333.67 ±12.35	361.00 ±13.20	325.87 ±2.82	329.78 ± 0.94
RDF (Control)	313.67 ±5.90	311.00 ±5.29	315.20 ±2.94	318.76 ± 3.61
Farmer Practice	283.33 ±7.22	293.00 ±3.79	305.96 ±3.39	309.33 ± 3.86
$C.D._{0.05}$	29.67	32.49	11.36	12.55



Graph 1: Effect of Zn application on Protein content % in seed



Graph 2: Effect of Zn application on oil content % in seed

Fig 1: Effect of Zn applications on Protein contents (%) in seeds

Fig 2: Effect of Zn applications on Oil contents (%) in seeds

Mechanism behind increase in oil content after the application of $ZnSO_4$ might be that Zn functions as metal activator of different enzymes such as glyceric glycine dipeptidase, di-hydropeptidase and cysteine di-sulphydrase. When Zn is applied at optimum dose it might have activated oil producing enzymes resulting in higher oil content and in turn oil yield in this study. The results are supported by the findings of Khan et al (2003), Deo and Khandelwal (2009) and Singh and Singh (2017 a). Regarding protein content, $ZnSO_4$ application increased protein content as it is involved in the metabolism of nitrogen hence might have lead to increase in protein content. Protein yield also followed the same trend as seed yield, this increase might be due to the increase in protein content but it must also be added that protein content in seed also has genetic and biochemical basis. In this particular case increase in seed yield also enhanced the protein yield. The results are similar to the results of Singh and Singh (2017 a) and Bhadauria et al (2012) who also observed increase in oil content, oil yield, protein content and protein yield after the application of $ZnSO_4$.

After analyzing the soil samples from the plots of different treatments it was observed that $ZnSO_4$ application had significant effect on soil properties. The data in the table 11 depicts that RDF + $ZnSO_4$ 25 kg/ha was most effective in increasing the OC (organic carbon) during the period of two years. Concerning available N, available P and available K (Table 11, 12) a similar trend was observed and highest values for available N, available P and available K was recorded from the treatment RDF + $ZnSO_4$ 25 kg/ha which was 10 % and 16 % (for N), 23 % and 11 % (for P), 13 % and 12 % (for K), respectively, higher as compared to farmer's practice. Similarly, for available S and Zn (Table 13), highest values was recorded from RDF + $ZnSO_4$ 25 kg/ha which was 44 % and 52 % (for available S) and 7 % and 10 % (for available Zn) higher when compared to farmer's practice. The effect of $ZnSO_4$ on fertility status of P was not significant this might be because of the antagonistic effect of Zn on phosphorus. However significant difference was observed in case of S and Zn. This might be because of the fact that application of $ZnSO_4$ acted as additional source of Zn and S which increased the status of available S and Zn in the soil. The results are in agreement with Singh and Singh (2017 a) in mustard.

Table 11: Effect of Zn application on available OC and N

	Available OC		Available N	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	1.50 ±0.06	1.70 ±0.06	465.00 ±2.89	512.00 ±6.08
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	1.30 ±0.06	1.50 ±0.06	450.00 ±4.00	487.00 ±5.20
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	1.40 ±0.06	1.60 ±0.06	454.00 ±2.52	476.00 ±2.31
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	1.30 ±0.06	1.50 ±0.06	446.00 ±2.65	458.00 ±2.08
RDF (Control)	1.20 ±0.06	1.20 ±0.06	448.00 ±4.16	457.00 ±2.52
Farmer Practice	1.40 ±0.06	1.50 ±0.06	421.00 ±1.73	441.00 ±4.16
C.D. $_{0.05}$	0.15	0.18	9.34	13.00

Table 12: Effect of Zn application on available P and K

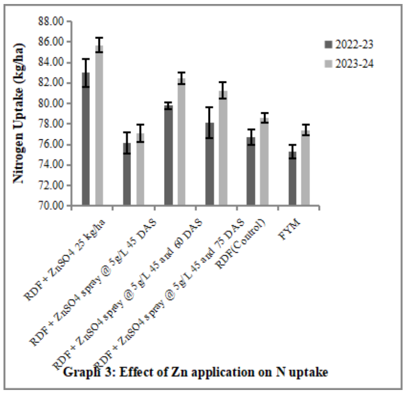
	Available P		Available K	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	48.00 ±2.08	51.00 ±1.16	248.00 ±2.52	251.00 ±2.65
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	45.00 ±2.65	46.00 ±1.73	236.00 ±1.53	237.00 ±2.65
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	46.00 ±1.73	48.00 ±2.08	249.00 ±2.08	250.00 ±2.52
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	42.00 ±2.08	45.00 ±2.65	234.00 ±5.03	233.00 ±3.22
RDF (Control)	41.00 ±0.58	45.00 ±1.73	231.00 ±2.65	229.00 ±1.53
Farmer Practice	39.00 ±2.08	45.00 ±2.31	218.67 ±1.86	224.00 ±5.03
C.D. $_{0.05}$	N/A	N/A	9.33	10.32

Table 13: Effect of Zn application on available S and Zn

	Available S		Available Zn	
Treatment	2022-23	2023-24	2022-23	2023-24
RDF + $ZnSO_4$ (Soil 25 kg/ha)	26.00 ±0.58	29.00 ±0.58	1.37 ±0.02	1.42 ±0.01
RDF + $ZnSO_4$ (FA 5g/L, 45 DAS)	23.00 ±2.08	25.00 ±1.00	1.32 ±0.03	1.34 ±0.02
RDF + $ZnSO_4$ (FA 5g/L, 45 & 60 DAS)	25.00 ±2.08	29.00 ±1.00	1.34 ±0.02	1.36 ±0.01
RDF + $ZnSO_4$ (FA 5g/L 45 & 75 DAS)	24.00 ±0.58	28.00 ±1.16	1.34 ±0.03	1.37 ±0.01
RDF (Control)	22.00 ±1.16	24.00 ±0.58	1.25 ±0.02	1.23 ±0.02

Farmer Practice	18.00 ±1.16	19.00 ±1.16	1.27 ±0.01	1.28 ±0.01
C.D. $_{0.05}$	4.61	2.54	0.07	0.04

The application of $ZnSO_4$ had significant effect on uptake of nutrients and it was observed that the highest uptake of all the nutrients i.e. N, P, K, S and Zn (Figs 3-7) was from the plots in which RDF + $ZnSO_4$ 25 kg/ha was applied. The increase of 10.2 % and 10.7 % (N), 24 % and 18 % (P), 21 % and 14 % (K), 22 % and 29 % (S) and 35 % and 29 % (Zn) treatment enhanced.



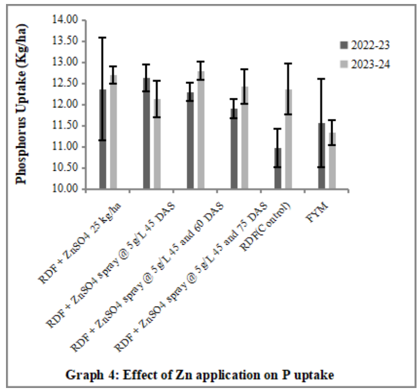
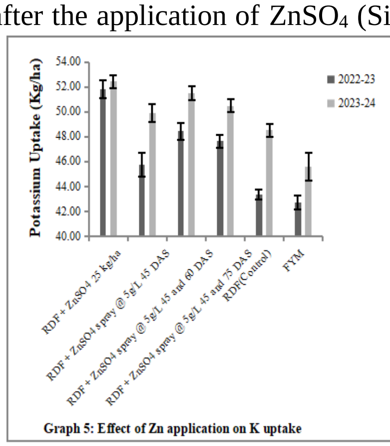


Fig 3: Effect of Zn applications on N uptake **Fig 4: Effect of Zn applications on P uptake**

Zn has positive effect on photosynthesis and metabolic processes because of which plant with sufficient Zn has higher production of photosynthetic assimilates and transportation to plant parts, thus increasing the uptake of N in mustard. Similar results were obtained by Singh and Singh (2017 a) in mustard, Singh and Singh (2017 b) in maize and Singh et al., (2008) in rice and wheat. There was no significant effect on uptake of P, as Zn and P are antagonistic in nature however a non significant increase was observed which might be due to increase in yields after the application of $ZnSO_4$ (Singh and Singh, 2017 a). Jat and Mehra (2007) also reported the similar findings. K, Zn and S uptake was significantly affected by application of $ZnSO_4$ as adequate quantity of Zn helps the plants to function better metabolically, thus increasing the uptake of the nutrients. The root growth is also promoted which might have augmented in the uptake of nutrients in the present study. In addition to that, readily available Zn as $ZnSO_4$ helped in increasing the Zn uptake by mustard plants. The results are supported by Singh and Singh (2017 a), Jat and Mehra (2007) and Upadhyay (2012) in mustard.



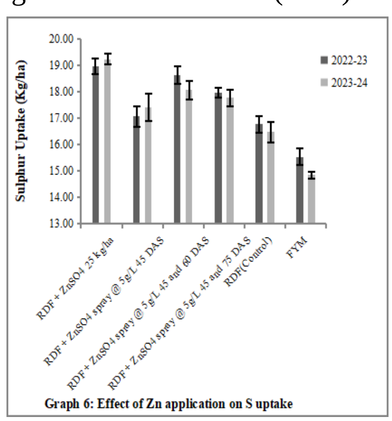
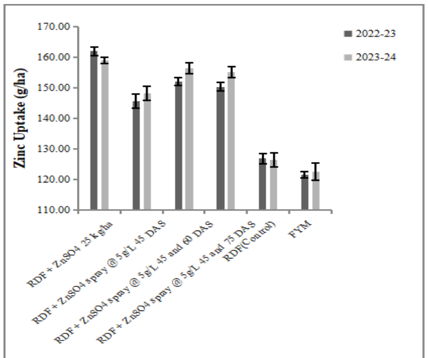


Fig 5: Effect of Zn applications on K uptake **Fig 6: Effect of Zn applications on S uptake**



Graph 7: Effect of Zn application on Zn uptake

Fig 7: Effect of Zn applications on Zn uptake

Thus, it can be concluded from the present investigation that the treatments i.e. soil application of $ZnSO_4$ @ 25 kg/ha and foliar application of $ZnSO_4$ @ 5g/L at 45 and 60 days after sowing were most effective treatments in enhancing yield, oil content and seed quality parameters in Gobhi sarson var. GSC-7.

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