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Application of Sulphur and Foliar Zinc at Different Growth Stages to Boost the Quality and Yield of Gobhi Sarson (*Brassica napus* L.) under Central Plain Region of Punjab, India

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ABSTRACT

Background: A key element for the growth of oilseed crops is sulphur. It is required for the synthesis of vitamins, oilsand proteins. Compared to the organic form, inorganic sulphur is less common in agricultural soils. Zinc contributes significantly to the regulatory cofactors of many enzymes and proteins in many biochemical processes, which can aid in the oilseed crop's high production. By 2025, there will be a 63% increase in Zn deficiency, up from 42% in 1970.

Methods: A field experiment was conducted for two years (2022-2023 and 2023-2024) at Agronomy Research Field, Lovely Professional University, Phagwara, Punjab, India, which comprises four zinc application (Dose @ 1.5 ml L^{-1}) treatments *viz*., Z_0-Control, Z_1-1 appl. (one spray @ 15 DAS), Z_2-2 appl. (two spray @ 15+45 DAS) and Z_3-3 appl. (three spray @ 15+45+75 DAS)and four sulphur application treatments *viz*., S_0-Control, S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}) and S_3 (30 kg ha^{-1}).

Result: The seed yield, stover yield, biological yield, harvest index, oil content and oil yield of gobhi sarson were studied. The application of zinc and sulphur had significant effect on seed yield, stover yield, biological yield, oil content and oil yield. The maximum seed yield (2752 kg ha^{-1}), stover yield (6841 kg ha^{-1}), biological yield (9593 kg ha^{-1}), oil yield (1112.40 kg ha^{-1}) recorded under Z_3-3 appl. (three spray @ 15+45+75 DAS) + S_3 (30 kg ha^{-1}) in comparison to other treatments. Application of sulphur 30 kg ha^{-1} recorded highest oil content and oil yield (40.25%, 962.32 kg ha^{-1}) in comparison to S_2-20 kg ha^{-1} (40.09%, 921.25 kg ha^{-1}), S_1-10 kg ha^{-1} (38.18%, 802.17 kg ha^{-1}), S_0-Control (36.21%, 689.17 kg ha^{-1}.

Key words: DAS (days after sowing), Oil content, Oil yield, Seed yield, Sulphur, Zinc.

INTRODUCTION

Oilseeds hold a distinguished position in Indian agriculture as a result of their critical contribution to the nation's sustainable economy. Edible vegetable oil is important for human nutrition. Edible oil, which has high energy content, is crucial for supplying humans with the calories they need. One of the most significant winter oil seed crops is Indian mustard. Due to a lack of accurate knowledge on its nutritional needs, mustard output is not effectively utilised. With a yield of 9.12 MT and an average productivity of 1586 kg/ha, Indian rapeseed and mustard grow on an area of around 7.2 million hectares (Anonymous, 2020).

An important nutrient for the growth of oilseeds is sulphur. With an average concentration of 0.06 percent, it ranks as the 13th most prevalent element in the crust of the planet. After nitrogen, phosphorusand potassium, sulphur (S) is becoming more widely acknowledged as the fourth main plant nutrient (Jamal *et al*., 2010). Depending on the crop, soiland environmental conditions, a hectare of oilseeds may remove 10 to 25 kg of sulphur annually, whereas a hectare of legumes can remove 5 to 10 kg (Singh and Singh, 2016). According to Singh 2001, almost 41% of soils in India have a sulphur deficiency. Rapeseed is more susceptible to sulphur deficit than other crops like cereals or legumes because of its high sulphur need (Zhao *et al*., 1997). The visual symptoms of sulphur deficiency in cruciferous crops are very specific and can be treated in the field throughout the growing season (Pierre *et al*., 1999). During flowering, the characteristic changes in sulphur deficiency in the color and shape of the petals (Haneklaus *et al*., 1999).

A lack of sulphur causes a build-up of amino acids, which is expected to control how well nitrogen is absorbed and assimilated. In contrast, activities that boosts the regeneration of organic sulphur result in compounds that act as defences against stress and as solutions. A severe sulphur deficit can eventually result in slower development, which is notably linked to a slower rate of epidemic spread

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(Hawkesford and De Kok, 2006). According to De Pascale *et al.* (2008), sulphur deprivation also causes a 40% decrease in the quantity and quality of rapeseed or oilseeds.

For plants to thrive at their best, a N:S ratio of around 20:1 is necessary (Cram, 1990). When sulphur is insufficient, accumulation of non-protein substances such amides happens, increasing the N:S ratio. In addition, sulphate builds accumulated in plant tissues when the supply of S exceeds that needed for protein synthesis (Reneau *et al*., 1986). This results in a reduced N:S ratio. The N:S ratio determines whether proteins are available or lacking in S. According to Spencer and Freney 1980, the N and S ratio is typically used as a diagnostic standard for S deficit. The N:S ratio can be found in tissues at a variety of various concentration levels, Schnug and Hanklaus 2000 noted, making its use as a diagnostic criteria less than ideal. Due to the ongoing loss of soil fertility, Zn deficiency in Indian soils is predicted to rise from 42 per cent in 1970 to 63 percent by 2025 (Singh, 2011). According to Jena *et al*., (2008), the zinc deficit in alluvial soils varied from 7.0 to 76.0 percent, 2 to 12 per cent in lateriteand 42 per cent in black soils. Black, mixed black and redand alluvial soils tend to be more zinc deficient than other soil types, according to (Sahu and Mitra, 1992). Zn deficit is due to Zn precipitating as hydroxide, carbonate and sulphide and to its adsorption on newly produced oxides of Fe with the highest surface area. Increased clay and silt concentration reduced the Zn-supplying ability of rice soils (Pal *et al.,* 2021). Studies have shown that sulphur and zinc fertilization significantly improve soybean growth and yield attributes. Specifically, the application of both nutrients enhanced plant height, pod number, seed yieldand stover yield (Imsong *et al.,* 2023). In acidic Alfisols and Inceptisols, phosphorus levels up to 120 mg P kg^{-1} significantly enhanced rapeseed yield and phosphorus uptake, with single super phosphate performing better than Mussoorie rock phosphate (Maurya *et al*., 2023).

In India, rainfed conditions are mostly used for oilseed crop cultivation. Because oilseed crops are grown in soils with marginal to poor fertility, their average productivity is low. The availability of Zn is poor in more than 30% of agricultural soils worldwide, which reduces crop yields and productivity (Alloway, 2009). Malnutrition is thus brought on among those lacking in resources (Singh, 2011). In order to fulfil the rising demand for oilseeds, average production levels must rise from the current 1292 kg/ha to 1450 kg ha^{-1} by 2025.

In India, oilseed crops account for 5.98% of the value of all agricultural products and about 3% of the country's GDP. According to Varaprasad *et al.* (2011), India accounts for 12 to 15 per cent of the world's oilseed area, 6-7 per cent of vegetable oil production, 9 to 10 per cent of all edible oil consumptionand 13.6 per cent of vegetable oil imports. Generally seven edible oilseed crops, *viz*., groundnut (*Arachis hypogaea*), mustard (*Brassica juncea* L.), soyabean (*Glycine max*), sunflower (*Helianthus annus*), safflower (*Carthamus tinctorius*), sesame (*Seasamum indicum*) and niger (*Guizotia abyssinica*) and two non-edible oilseed crops, *viz*. Castor (*Ricinus communis*) and linseed (*Linum usitatissimum*) are grown. Organic manures, such as vermicompost and pressmud, improved the seed quality, including oil and protein content. Overall, the integration of foliar sulphur with organic and inorganic fertilizers improved both the yield and quality of canola, offering a sustainable approach for better production and soil health (Singh *et al*., 2020).

The productivity of oilseed is much lower than the global average (1.9 t ha^{-1}) and that of emerging nations (2.5 - 3.0 t ha^{-1}). Low productivity is mostly caused by improper or uneven fertiliser use, farming on marginal soilsand rainfed conditions (Tripathi *et al*., 2010). Therefore, there is a significant disparity between the demand for and production of mustard in our nation, or low productivity may be caused by oilseed crops continuously depleting the soil of its nutrients (Sudhakara and Hegde, 2011; Pant *et al*.,2022). Therefore, improving sulphur and zinc utilisation and managing soil-crop-sulphur-zinc fertilisation are urgently needed to boost mustard crop yield. The goal of the current study was to determine the effects of zinc and sulphur nutrition on yield and quality of gobhi sarson.

Materials and Methods

The study was carried out for a period of two years at the Research Farm, Lovely Professional Universityand Phagwara, Punjab, India (31°14′35.2″N latitude and 75°41′48.2″ E longitude). The experiment location is in a semi-arid, subtropical climate zone. Summer temperatures ranged from 24 to 46.5°C and winter temperatures varied from 3.6 to 26°C. The majority of the yearly rainfall is anticipated during the monsoon season (July to September)and ranges from 500 to 800 mm on average. In the soil, the water is around 90-100 m below the surface. The soil composition of the region classified as Central alluvial plain or sandy loam, the soil surface, 0-15 cm, had a pH (7.65), EC (0.45 dS m^{-1}), medium SOC (0.57%)and also low status of available N, P_2O_5, K_2O, S and Zn (185.7, 24.9, 198.5 kg ha^{-1}, 8.50 and 0.46 mg kg^{-1} respectively), for initial soil samples in October 2022.

The experiment was conducted with two factor zinc spray (through zinc oxide 39.5% Zn, 1.5 ml L^{-1}) and sulphur (through bentonite sulphur 90%) soil application comprised of Z_0-Control, Z_1-1 appl. (one spray @ 15 DAS), Z_2-2 appl. (two spray @ 15 + 45 DAS) and Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS)and four sulphur application treatments *viz*., S_0-Control, S_1 (10 kg ha^{-1}), S_2 (20 kg ha^{-1}) and S_3 (30 kg ha^{-1}), were tested in factorial randomized block design replicated 3 times and recommended dose of fertilizer N, P_2O_5, K_2O (40:12:40) was applied and test variety was GSC-7. For determination of oil content (%) in the seed, determined by using a Soxhlet apparatus (AOAC, 2005). The oil yield determined by multiplying the seed yield with the

appropriate oil content using mathematical calculation. Regularly biometric observations were recorded at specific time intervals by selecting randomly five plants in each treatment. Finally, the crop was harvested and produce was dried, threshed, cleaned and weighed. The yield data were subjected to statistical analysis.

Data presented in tables were two-year pooled data; the results were similar for both years and pooled data provided the best representation of the observed results. Utilizing window-based statistical software, SPSS version 16.0 using zinc application and sulphur application as factors (SPSS 2018). The data for yield and quality of gobhi sarson were analyzed using a factorial randomized block design (FRBD) with Duncan's multiple range Test at a 5% level of significance for comparing the means.

Results and Discussion

Seed yield, stover yield, biological yield and harvest index

The application of zinc and sulphur had significant effect of seed yield, stover yield and biological yield (Table 1). The seed yield treatments with zinc application ranges from 2425 to 1800 kg ha^{-1}, The Z_0-control treatment had the lowest seed yield, whereas the maximum (2425 kg ha^{-1}) was recorded under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS). The application of sulphur 30 kg ha^{-1} (2390 kg ha^{-1}) recorded maximum seed yield. The interactive effect of zinc and sulphur application on seed yield was found significant. The maximum seed yield (2752 kg ha^{-1}) under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) + S_3 (30 kg ha^{-1}) followed by (2647 kg ha^{-1}) Z_2-2 appl. (two spray @ 15 + 45 DAS) + S_3 (30 kg ha^{-1}).

The application of zinc and sulphur significantly altered stover yield of gobhi sarson (Table 1). The maximum stover yield (5873 kg ha^{-1}) under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) followed by Z_2-2 appl. (two spray @ 15 + 45 DAS) and lowest under Z_0-Control (4556 kg ha^{-1}). The stover yield in the treatments of sulphur application, in decreasing order, was as follows: S_3-30 kg ha^{-1} (6065 kg ha^{-1}), S_2-20 kg ha^{-1} (5621 kg ha^{-1}), S_1-10 kg ha^{-1} (5107 kg ha^{-1}) and lest in S_0-Control (4580 kg ha^{-1}). The interactive effect of zinc and sulphur application on stover was found significant. The maximum stover yield (6841 kg ha^{-1}) under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) + S_3 (30 kg ha^{-1}) followed (6597 kg ha^{-1}) by Z_2-2 appl. (two spray @ 15 + 45 DAS) + S_3 (30 kg ha^{-1}) and lowest under (4161 kg ha^{-1}) Z_0-Control + S_0-Control.

Similar to seed yield and stover yield, various zinc and sulphur application treatments had a significant effect on the biological yield of gobhi sarson (Table 1), the interactive effect of zinc and sulphur was also found significant. The maximum biological yield (9593 kg ha^{-1}) under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) + S_3 (30 kg ha^{-1}) followed (9244 kg ha^{-1}) by Z_2-2 appl. (two spray @ 15 + 45 DAS) + S_3 (30 kg ha^{-1}) and lowest under (5817 kg ha^{-1}) Z_0-Control + S_0-Control. The application of zinc and sulphur had non-significant effect on harvest index.

Oil content and oil yield

Different zinc and sulphur application treatments had considerable effect on oil content and oil yield (Table 2). The maximum oil content and oil yield was recorded (38.85%, 946.36 kg ha^{-1}) under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) followed by Z_2-2 appl. (two spray @ 15 + 45 DAS) (38.15%, 919.32 kg ha^{-1}), Z_1-1 appl. (one spray @ 15 DAS) (37.24%, 816.32 kg ha^{-1})and least under Z_0-Control (36.40%, 692.71 kg ha^{-1}), respectively. Application of sulphur 30 kg ha^{-1} recorded highest oil content and oil yield (40.25%, 962.32 kg ha^{-1}) in comparison to S_2-20 kg ha^{-1} (40.09%, 921.25 kg ha^{-1}), S_1-10 kg ha^{-1} (38.18%, 802.17 kg ha^{-1}), S_0-Control (36.21%, 689.17 kg ha^{-1}).

The graphical representation showed that, application of zinc and sulphur had significant interactive effect on oil yield (Fig 1). The highest oil yield (1112.40 kg ha^{-1}) under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) + S_3 (30 kg ha^{-1}) followed (1068.50 kg ha^{-1}) by Z_2-2 appl. (two spray @ 15 + 45 DAS) + S_3 (30 kg ha^{-1}) and lowest under (595.25 kg ha^{-1}) Z_0-Control + S_0-Control.

Applications of sulphur and other nutrients greatly enhanced the oil content (15- 30 per cent) in oilseed crops as groundnut, rapeseed–mustard, *etc.* (Ahmad *et al.*, 1999).

Table 1: Response of zinc application and sulphur levels on seed yield, stover yield, biological yield and harvest index of Gobhi sarson.

Treatments	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
Zinc application				
Z_0- Control	1800^{c}	4556^{c}	6355^{c}	28.32^{ab}
Z_1- 1 appl.	2106^{b}	5209^{b}	7316^{b}	28.90^{ab}
Z_2- 2 appl.	2358^{a}	5736^{a}	8094^{ab}	29.13^{a}
Z_3- 3 appl.	2425^{a}	5873^{a}	8297^{a}	29.25^{a}
Sulphur levels				
S_0- Control	1903^{d}	4580^{d}	6483^{d}	29.34^{a}
S_1- 10 kg/ha	2100^{c}	5107^{c}	7207^{c}	29.10^{a}
S_2- 20 kg/ha	2297^{ab}	5621^{b}	7918^{b}	28.94^{a}
S_3- 30 kg/ha	2390^{a}	6065^{a}	8455^{a}	28.23^{a}

In the table, the same letters indicate no significant difference ($p > 0.05$) by Duncan's multiple range test (DMRT).

Sulphur application accelerates the plant's process of synthesising proteins (Ahmad and Abdin, 2000). Through sulphur nutrition, the composition of oil, acetyl-CoAand acetyl-CoA carboxylase in oilseeds is also impacted. The amount of various fatty acids in a particular oilseed impacts its application; for example, linseed oil with a high linolenic acid content is advantageous for the high-quality production of paints and other products. In addition to this, sulphur administration speeds up the production of linolenic acid and causes less stearic, oleicand linoleic acid to be produced (Ahmad *et al*., 2006; Pant *et al*., 2022).

This resulted from sufficient S availability, as S is a structural element of glucosinolate, the enzyme glycosidase (Thompson *et al*., 1986), a component of acetyl-CoA carboxylaseand glycerol, which are all involved in mustard's increased synthesis of fatty acids and oils (Fazli *et al*., 2005; Pant *et al*., 2022). The oil content was significantly impacted by foliar spraying zinc and B as well as varying soil levels. This could be because applying zinc to mustard crops increases the amount of assimilate that seeds receive, which in turn increases the amount of fat synthesis and oil content. Activation of multiple enzymes, including cysteine desulphydrase, NADPH dehydrogenase, glycyl-glycine dipeptidaseand dihydropeptodase, may also be the cause (Iweive and Weiner, 1972; Havlin *et al*., 2013; Pant *et al*., 2022).

Table 2: Response of zinc application and sulphur levels on oil content and oil yield of Gobhi sarson.

Treatments	Oil content (%)	Oil yield (kg ha^{-1})
Zinc application		
Z_0- Control	36.40^{c}	692.71^{c}
Z_1- 1 appl.	37.24^{b}	816.53^{b}
Z_2- 2 appl.	38.15^{ab}	919.32^{a}
Z_3- 3 appl.	38.85^{a}	946.36^{a}
Sulphur levels		
S_0- Control	36.21^{c}	689.18^{c}
S_1- 10 kg/ha	38.18^{b}	802.17^{b}
S_2- 20 kg/ha	40.09^{a}	921.25^{a}
S_3- 30 kg/ha	40.25^{a}	962.32^{a}

In the table, the same letters indicate no significant difference (p>0.05) by Duncan's multiple range test (DMRT).

Seed yield, stover yield, biological yield and harvest index

Sulphur is essential for the production of cysteine, methionine, chlorophyll, vitamins (B, biotinand thiamine), as well as for the metabolism of carbohydrates, oilsand proteins. It is also linked to growth and metabolism, particularly for its impact on protolytic enzymes (Najar *et al*., 2011; Pant *et al*., 2022; Ahmad *et al*., 1999; Ahmad *et al*., 2006). Additionally, increased protein synthesis, glucose metabolismand photosynthate translocation with S administration are to blame (Thompson *et al*., 1989).

Alloway, (2008) states that while B assisted in the development of reproductive structures and the translocation of photosynthates toward sinks, Zn fertilization increased the activity of several enzymes involved in photosynthesis, CO_2 assimilation, starch formationand protein synthesis (Shireen *et al*., 2018). According to Singh *et al*. (2010), there was a discernible increase in 1000-seed weight, seed productionand stover output of up to 30 kg S ha^{-1}. Application of 40 kg S ha^{-1} resulted in considerably better seed and stover production, according to Dubey *et al*. (2013). It might be the result of the crop's increased capacity for photosynthetic respiration after applying S, which aided in the production of

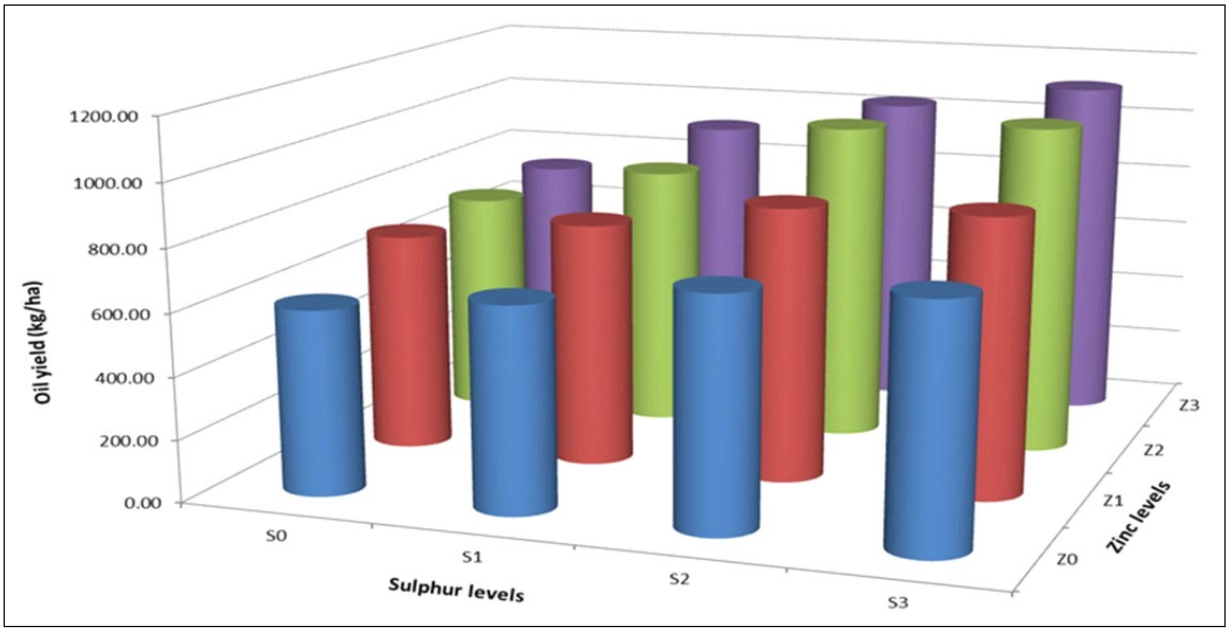


Fig 1: Interactive effect of zinc and sulphur application on oil yield of gobhi sarson.

chlorophyll, protein synthesisand effective nitrogen utilization. This could account for the mustard crop's increased plant growth and dry matter accumulation (Thompson *et al*. 1989; Ahmad and Abdin, 2000).

Oil content and oil yield

This resulted from sufficient S availability, as S is a structural element of glucosinolate, the enzyme glycosidase (Thompson *et al*., 1986), a component of acetyl-CoA carboxylaseand glycerol, which are all involved in mustard's increased synthesis of fatty acids and oils (Fazli *et al*., 2005; Pant *et al*., 2022). The oil content was significantly impacted by foliar spraying zinc and B as well as varying soil levels. This could be because applying zinc to mustard crops increases the amount of assimilate that seeds receive, which in turn increases the amount of fat synthesis and oil content. Activation of multiple enzymes, including cysteine desulphydrase, NADPH dehydrogenase, glycyl-glycine dipeptidaseand dihydropeptodase, may also be the cause (Iweive and Weiner, 1972; Havlin *et al*., 2013; Pant *et al*., 2022).

CONCLUSION

Oilseed production in India continues to be poor as a result of a significant propagation deficit and low S and Zn fertiliser usage. The findings of soil tests can be utilised to create nutrient maps for zinc and sulphur for balanced management in a farmer's field. The maximum seed yield (2752 kg ha^{-1}), stover yield (6841 kg ha^{-1}), biological yield (9593 kg ha^{-1}), oil yield (1112.40 kg ha^{-1}) recorded under Z_3-3 appl. (three spray @ 15 + 45 + 75 DAS) + S_3 (30 kg ha^{-1}) in comparison to other treatments. Application of sulphur 30 kg ha^{-1} recorded highest oil content and oil yield (40.25%, 962.32 kg ha^{-1}) in comparison to S_2-20 kg ha^{-1} (40.09%, 921.25 kg ha^{-1}), S_1-10 kg ha^{-1}(38.18%, 802.17 kg ha^{-1}), S_0-Control (36.21%, 689.17 kg ha^{-1}.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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