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Enhanced oil quality, yield, economics, and nutrient uptake in Indian mustard (*Brassica juncea* L.) varieties via sulphur management

[1]Pradeep Kumar, [1]Majhrool Hak Ansari, [2]Rajeev Kumar and [3]Anand Kumar Jain

[1]Assistant Professor-cum- junior Scientist, Department of agronomy, VKSCOA, Dumraon, Buxar, Bihar Agricultural University, Sabour, Bihar, India

[2]Assistant Professor, School of Agriculture, Sanskriti University, Mathura, Uttar Pradesh, India

[43]Assistant Professor, Department of Agronomy Pulse Research Centre, Mokama, Bihar, India

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Corresponding Author: Majhrool Hak Ansari

Abstract

India mustard (*Brassica juncea* L.) is an essential oilseed crop that offers important nutrients to human beings. However, the concurrent micronutrients deficiencies including sulphur (S) and other nutrient could pose a significant important to public health. Therefore, a field experiment was conducted at agronomy Research farm of Acharya Narendra Deva University of Agriculture and Technology, Ayodhya (Uttar Pradesh) during the rabi of 2010-11. Twelve treatments comprised of four levels of sulphur (0, 20, 40, and 60 kg S ha^{-1}) and three varieties (Varuna, Vardan and Ashirwad) were arranged in randomized block design with three replication. The soil of experimental field was silty loam in texture slight alkaline in reaction having low organic carbon and available nitrogen and medium in phosphorus and high in potash. The crop recorded normal recommended cultural and plant protection measures. Application of 60 kg S ha^{-1} produced significantly higher values of plant, high primary and secondary branches plant^{-1}, leaf area index, number of siliqua plant^{-1}, length of siliqua, number of seeds siliqua^{-1}, harvest index and oil content. However, dry matter accumulation plant^{-1}, 1000-seeds weight, biological yield, seed yield, stover yield and protein content was significantly increased with increasing dose of sulphur upto 40 kg ha^{-1}. Varuna fertilized with 40 kg S ha^{-1} gave highest yield, net return and highest benefit cost ratio (1.10) against lowest net return obtained from unfertilized Vardan.

Keywords: Oil quality, Indian mustard, sulphur, nitrogen, yield, nutritional uptake

Introduction

India is one of the largest rapeseed-mustard growing countries in the world, occupying the first position in area and second position in production after China. The world production of Rapeseed/mustard has been increasing at a rapid rate in several countries largely in response to the continuing increase in demand for edible oils and its products.

Brassica (Rapeseed-mustard) is the second most important edible oil seed crop in India after groundnut and accounts for nearly 30 per cent of the total oilseeds production and 13 per cent of the country's gross cropped area. When compared to other edible oils, the rapeseed/mustard oil has the lowest amount of harmful saturated fatty acid Singh and Kumar (2014) [30]. It also contains adequate amount of the two essential fatty acid, linoleic and linolenic which are not present in many of the other edible oils. Rapeseed-mustard seed was primarily used for human consumption because of low erucic acid and thus, becoming desirable edible oil. With the invention of steam power, it was found that the oil could be used as a lubricant that would cleaning water steam-washed metal surfaces better than any other lubricant. (Kumar *et al*., 2014) [16].

India and China are the two major consumers of rapeseed-mustard. In India, consumption of Rapeseed/mustard and its oil is generally high in northern states. The vegetable oil situation is quite complicated and is heavily impacted by market factors, competing interests, the vagaries of weather, technology and numerous biotic and abiotic pressures. Despite impressive progress of the vegetable oil sector in the last two decades, the import during the last 7-8 years has been continuously rising. During 2003-2004, even with record oilseeds production of 25.10 million tonnes, India imported 51 lakh tonnes of vegetable oils costing more than Rs. 11, 000 crores to the exchequer (Meena *et al*., 2018) [19].

The oil of rapeseed-mustard crop serves as a very important cooking medium and dietary fat and potassium, the seed and oil yield and quantity are not reaching its full potential probably because of the increased requirements of sulphur induced by use of sulphur free fertilizers (Bañuelos *et al*., 2002) [3].

The oilseed crops especially Brassica species play a vital role in the agriculture economy of India. Among these, *Brassica juncea* is an important Rabi crop of eastern India comprising Uttar Pradesh, Bihar, West Bengal and Assam. India occupies the third position in Rapeseed-mustard production in world after China and Canada. In India, during 2009-10, the Rapeseed/ mustard crop had production of 6.40 mt from an area of 6.45 million hectares with an average productivity of 990 kg ha^{-1}. However, in Uttar

Pradesh it is grown on 0.82 million hectares area with production of 0.90 million tonnes. The average productivity of Uttar Pradesh is 1141 kg ha^{-1} which is more than the national average productivity.

Indian mustard is highly sensitive to nitrogen (N), and sulphur (S) deficiency, thereby resulting in a decreased growth, yield, and productivity of the crop (Vanisha *et al.*, 2013; Sanwal *et al.*, 2016) [35, 24]. The introduction of high-yielding cultivars increases cropping intensity, whereas the application of micronutrient-free fertilizers and limited the addition of organic manures leads to S deficiency in most of the Indian soils. Suphur deficiency is one of the major constraints to oil seed production (Sillanpaa, 1982; Dhaliwal *et al.*, 2022) [26, 7]. Its deficiency has been realized as the second most important micronutrient constraint in crops on the global scale (Ahmad *et al.*, 2012) [1]. Improved plant types play an important role in raising the seed yield of the crops. Development of high yielding varieties of mustard has been one of the major concerns of the scientists because use of the improved varieties alone accounts for 15-20 per cent increase in productivity (Dhaliwal *et al.*, 2022) [7]. This is probably because of their altered morphology which results into efficient utilization of water, nutrients and solar radiation.

In oilseed, sulphur plays a vital role in quality, production and plays an important role in protein synthesis of essential amino acids like cysteine and methionine. However, the information regarding optimum dose of sulphur and its influence on mustard is necessary to augment the productivity and quality of Indian mustard. Sulphur levels significant influenced the seed and stover yield of mustard (Sharma *et al.*, 2017) [40]. The chemical fertilizers being used for supplementing the major nutrient are generally either deficient or low in sulphur content.

Indian mustard markedly responded to sulphur fertilization in oilseeds, sulphur plays a vital role in quality and development of seed. The importance of sulphur fertilization for increasing yield and quality of Indian mustard is being increasingly recognized. However, the information regarding optimum level of sulphur and its influences on seed yield and quality of different varieties of mustard is meager (Gheith *et al*., 2022) [11]. Probably for these reasons mustard crop needs comparatively higher amount of sulphur for proper growth and development and higher yields.

The Indian soils have generally been reported to be low in nitrogen, phosphorus and sulphur. Because of multiple cropping and introduction of high yielding varieties, the deficiency of these nutrients in soil is becoming wider. The total sulphur content of Indian soil varies considerably ranging from 19 to 3836 ppm. So far its deficiency in soil has been reported from 65 countries and India is one of them of the 400 districts in India, sulphur deficiency has been reported in 90 districts (Tandon, 1986) [41]. The soil in most of the parts in Uttar Pradesh where oilseed crops grown are light or medium in texture, marginal to deficient in sulphur. Elemental sulphur encourages greater population of sulphur oxidizing micro-organisms and improves oxidizing power of soils upon their addition to the soils. The acidity produced by elemental sulphur is beneficial in the treatment of calcareous and high pH soil, particularly under irrigated condition. Some of benefits reported are reclaiming sodium or boron affected soils, increasing the availability of phosphorus and micro nutrients, reducing ammonia volatilization from irrigation water, increasing water penetration, controlling weeds and soil born pathogen (Tisdale *et al*., 1985) [35]

Sulphur is considered to occupy fourth place among major plant nutrient after nitrogen, phosphorus and potassium (Nyborg and Bently, 1977; Brogan and Murphy, 1980 and Mayer and Murcum, 1980) [22, 4, 18]. It increases phosphorus uptake by plant (Singh and Bairathi, 1980) [29] and nitrogen in protein synthesis and is indispensable for the synthesis of essential amino acid like cystein, cysteine and methionine. Besides, sulphur is also involved in various metabolic processes of plants. It is a constituent of glutathione, a compound supposed to be associated with the plant respiration and the synthesis of essential oils. Sulphur also plays a vital role in chlorophyll formation.

The present production is not adequate to meet the edible oil requirement of our fast growing population. A wide gap exists between the demand and supply resulting into a large scale import of fats and oils at the expense of valuable foreign exchange rapeseed-mustard is the most important rabi oilseed crop of Northern India grown mainly for edible oil requirement of our fast growing population, the efforts should be made to increase the production of oilseed crops. Rapeseed-mustard gives good response to sulphur (Zalak *et al.*, 2020) [27].

Materials and Methods

The present investigation was carried out during *Rabi* season of 2010-11 at Agronomy Research Farm of Acharya Narendra Deva University of Agriculture & Technology, Narendra Nagar (Kumarganj), Ayodhya (U.P.). The research farm is located in the main campus of the University. The field is located at left side and near the Ayodha - Raibareily main road at a distance of 42 km away from Ayodhya district head quarter. Geographically, this region falls under sub-tropical climate and its is situated at $26^0.47'$ N latitude $82^0.12'$ E longitude and an indo-gangetic alluvial of eastern Uttar Pradesh in India. The annual rainfall of this region is about 1100 mm of which 85% received during monsoon (mid June to end of September). However occasional showers are also not uncommon during winter. The winter months are cold and dry and occasional first occurs during the period. The temperature starts rising from the month of February onwards and continue to rise upto June. The hot winds blow from south-west to north - east during summer. The average weekly maximum and minimum temperatures during the crop growth period ranged from 14.3 and 35.8 and 2.5 to 15.7, respectively. The pH and EC of the soil were calculated following the method described by Jackson (1973) [14]. The wet combustion method was used to determine the organic carbon (OC) content in the soil (Walkey & Black, 1934**)** [34]. The experimental Silt loam soil possessed a pH of 8.2, and an OC of 3.7% and available S by the turbidimetric method (Williams and Stein berg, 1959) [38] were found to be 10.50 kg ha^{-1}, respectively. The alkaline $KMnO_4$ method, the Olsen extractable P method, and the Flame photometer method were used to estimate the available N, P, and K, respectively (Jackson, 1973) [14], where the values were 194.25 Kg ha^{-1}, 18.03 Kg $ha^{-1}$and 250.25 Kg ha^{-1} for N, P and K, respectively.

Treatment details

The experiment was conducted in Randomized Block Design (factorial) with three (3) replications. There were twelve treatment combinations consisted of 4 levels of sulphur and 3 genotypes were allocated randomly. The treatments were as under

A) Levels of sulphur (kg ha^{-1})

Levels of sulphur (kg ha^{-1})	Symbol
0 (No sulphur)	S_0
20	S_1
40	S_2
60	S_3

B) Genotypes

Genotypes	Symbol
Varuna	V_1
Vardan	V_2
Ashirvad	V_3

C) Treatment combinations

Treatments	Combination
T_1	V_1S_0
T_2	V_1S_1
T_3	V_1S_2
T_4	V_1S_3
T_5	V_2S_0
T_6	V_2S_1
T_7	V_2S_2
T_8	V_2S_3
T_9	V_3S_0
T_{10}	V_3S_1
T_{11}	V_3S_2
T_{12}	V_3S_3

The experiment was laid out in well prepared field as per layout plan. The experiment consisting of (12) twelve treatments were replicated three times randomly. There were 36 plots. Each plot having an area 4.40 × 2.40 m^2 and demarcated by 50 cm bound with adequate provision of irrigation channel. On the 120th day of physiological maturity, they were manually harvested in April where the seeds, as well as stover samples, were collected for examination.

Materials and methods

Site Specification and Characteristics

The study was conducted during (winter) Rabi seasons, of 2010 at the experimental farm located within the Department of agronomy, Acharya Narendra Deva University of Agriculture & Technology, Narendra Nagar (Kumarganj), Ayodhya (U.P.). The research farm is located in the main campus of the University. The field is located at left side and near the Ayodhya - Raibareily main road at a distance of 42 km away from Ayodhya district head quarter. Situated in the Indo-Gangetic plains of northern India, the farm's geographical coordinates are approximately 26^0.47′ N latitude 82^0.12′ E longitude, with an elevation of 98 meters above mean sea level. The research was carried out between the months of November and April. Soil pH and electrical conductivity (EC) were determined using the method outlined by Jackson (1973) [14]. Additionally, wet combustion methods were employed to organic carbon in the soil (Dhaliwal *et al.*, 2021a) [8] the soils was silt loam, containing 0.37% organic carbon, 194.5 kg available NAlkaline potassium permanganate methods (Subbiah & Asija, 1956) [32] 18.03 kg available P_2O_5 Olsen'smethod (Olesn *et al*., 1954) [21], 250.25 kg available K_2O ha^{-1}Flame photometer (Jackson, 1973) [14] and 10.50 available S Turbidimetric method (Williams and Stein berg, 1959) [38] in upper 30 cm soil depth. The region exhibited a subtropical climate along with hot, rainy summers as well as dry winters. The annual rainfall ranges from 1000 to 1100 mm. The average weekly maximum and minimum temperatures during the crop growth period ranged from 14.3 and 35.8 and 2.5 to 15.7, respectively during the crop seasons.

Treatment details

The study was performed with twelve treatments comprising of three genotypes of Indian mustard i.e. 'Varuna' (Type 59) 'Vardan' and 'Ashirwad' (RK-103), and four levels ofsulphur (0, 20, 40 and 60 kg S ha^{-1}) were evaluated in factorial randomized block design with three replication. All the treatments received N, P_2O_5 and K_2O @ 120, 60, and 40 kg ha^{-1} through urea, diammonium phosphate and muriate of potash respectively, sulphur doses were applied through elemental sulphur as treatments wise. Half dose of nitrogen along with full dose of phosphorus, potassium and sulphur were applied as basal dressing as per treatments and remaining dose of nitrogen was top dressed into two equal splits. 1st split was top dressed at 30 DAS and 2nd splits at pre flowering stage of the crop. The Indian mustard genotypes were sown in row at 30 cm distance on 10th November 2010. All standard agronomic practices were followed to harvest good crop yields and the crop was adequately protected from insect pests and diseases. Data on oil quality, yield, economics, and nutrient uptake were recorded as per standard procedures. For determination of sulphur in plants, ground plant material was digested withdiacid mixture having nitric and perchloric acid in 4:1 ratio.

Growth parameters

At physiological maturity, data regarding growth parameters such as plant height and the quantity of capsules per plant were recorded by calculating the average values from five plants within each plot. Plant height was measured using a meter scale from the plant's base to its tip, with the average height expressed in centimeters. The total count of capsules per plant was manually determined.

Oil content

Seed sample were kept in the oven at 70 ^{0}C for removal of moisture thereafter, the seeds ware ground in a pestle mortar for extraction of oil. The conventional soxhlet method was used for estimation of oil (A.O.A.C., 1995). The oil content was also estimated by Oxford Analytical Newport 4000 NMR Oil percent was calculated by using following formula

$$\text{Oil content (\%)} = \frac{\text{Weight of oil flask + ether extract} - \text{weight of flask oil}}{\text{Substances taken}} \times 100$$

Protein content (%)

For determination of protein content, seed samples of different treatment were analysed for nitrogen content in seeds (Measured by digesting samples with H_2SO_4 and total nitrogen was calculated by micro Kjeldahl's technique presented by Jackson, 1967) [13] by multiplying with a constant factor of 6.25 and it expressed in percentage. The protein yield was calculated by multiplying the seed yield with protein content in seeds.

Sulphur uptake (kg ha^{-1})

For determination of sulphur in plants, ground plant material was digested with diacid mixture having nitric and perchloric acid in 4.1 ratio. Digested plant materials were analysed for sulphur by turbidimetirc method (Chesnied and Yien, 1950) [6]. The percentage values obtained were multiplied by their corresponding dry weight and it expressed in kg ha^{-1}.

$$\text{Total sulphur uptake by the crop (kgha}^{-1}) = \text{Seed yield (kgha}^{-1}) \times \text{Sulphur content in seed(\%)} + \text{storeyield (kgha}^{-1}) \times \text{sulphur content in stover (\%)}$$

Economics

Cost of cultivation was worked out on one hectare basis economics of different treatments combinations was worked out by taking account the cost of cultivation and sale value of produce. Gross income was amounted by adding the revenues obtained from stover and seed yield. Net income of rupees was worked out by subtracting the total cost of cultivation from gross income.

The gross and net return as well as the net return rupee^{-1} invested was worked as follows for each treatments.

$$\text{Gross income} = \text{Monetary return seeds yield} + \text{stover yield (Rs ha}^{-1})$$

Net income = Gross return- total cost of cultivation (Rs ha^{-1})

Benefit cost ratio or net return rupee^{-1} invested was calculated by dividing the net return heactare^{-1} in rupees by the cost of cultivation hectare in rupees.

$$\text{Benefit} - \text{cost ratio} = \frac{\text{Net income (Rs ha}^{-1})}{\text{Total cost of cultivation (Rs ha}^{-1})}$$

Cost of cultivations

Cost of cultivation was worked out on one ha basis. Economics of different treatment was worked out by taking into account the cost of cultivation and sale value of produce. Gross income was worked out by multiplying per hectare seed and straw yield obtained under various treatments with the prevailing market selling rates. Net income in rupees was worked out by subtracting the total cost of cultivation from gross income.

The gross and net return as well as the net return rupee^{-1} invested was worked out as follows for each treatment.

Gross return = Monetary return seeds yield + stover yield (Rs. ha^{-1})

Net income = Gross return – total cost of cultivation (Rs. ha^{-1})

Benefit cost ratio or net return rupee^{-1} invested was calculated by dividing the net return hectare^{-1} in rupees by the cost of cultivation ha^{-1} in rupees-

$$\text{B: C ratio} = \frac{\text{Net return (Rs ha}^{-1})}{\text{Total cost of cultivation (Rsha}^{-1})}$$

Statistical analysis

The experimental data recorded in respect of different observations in the present experimental were analyses statistically with help of following procedure for Randomized Block Design (RBD) to test the significant of the overall differences among treatment by the F test and conclusion were drawn at 5% probability level, when 'F' value from analysis of variance table was found to be significant, the degree of treatment pertaining two various source of variation in the analysis of variance. The analysis of variance table is given blow**:**

The significance of treatment effects were assessed with help of "F test" of variance ratio. The standard error of mean was computed so follows.

$$\text{SEm}\pm = \sqrt{\frac{\text{Error variance (VE)}}{\text{(Replication d.f.x variety d.f.)}}}$$

$$\text{SEm} \pm \text{for variety} \sqrt{\frac{\text{Ve}}{\text{r} \times \text{s}}}$$

$$\text{SEm} \pm \text{for Sulphur} \sqrt{\frac{\text{Ve}}{\text{r} \times \text{v}}}$$

$$\text{SEm} \pm \text{for interaction effect (s} \times \text{v)} \sqrt{\frac{\text{Ve}}{\text{r}}}$$

$$\text{CD at 5\% for sulphur level} = \sqrt{2 \times \text{SEm} \pm \text{for sulphur levels} \times \text{t value at 5\% for error of d.f.}}$$

$$\text{CD at 5\% for Variety} = \sqrt{2 \times \text{SEm} \pm \text{for variety} \times \text{t value at 5\% for error of d.f.}}$$

$$\text{CD at 5\% for interaction effect} = \sqrt{2 \times \text{SEm} \pm \text{for interaction effect} \times \text{t value at 5\% for error of d.f.}}$$

The difference significant between treatments mean was tested against critical difference which was work out by the above formula.

Results

Basal application of different levels S affecting some quality and growth parameters of Indian mustard

Protein content

Result on the quality parameters of mustard seed Data presented in Table 1 the maximum protein content of 22.90 per cent was found in Vardan followed by 19.91 per cent in Ashirwad and 19.30 per cent in Varuna. The protein content of Vardan was significantly higher over Ashirwad and Varuna and later two remained at par varieties.

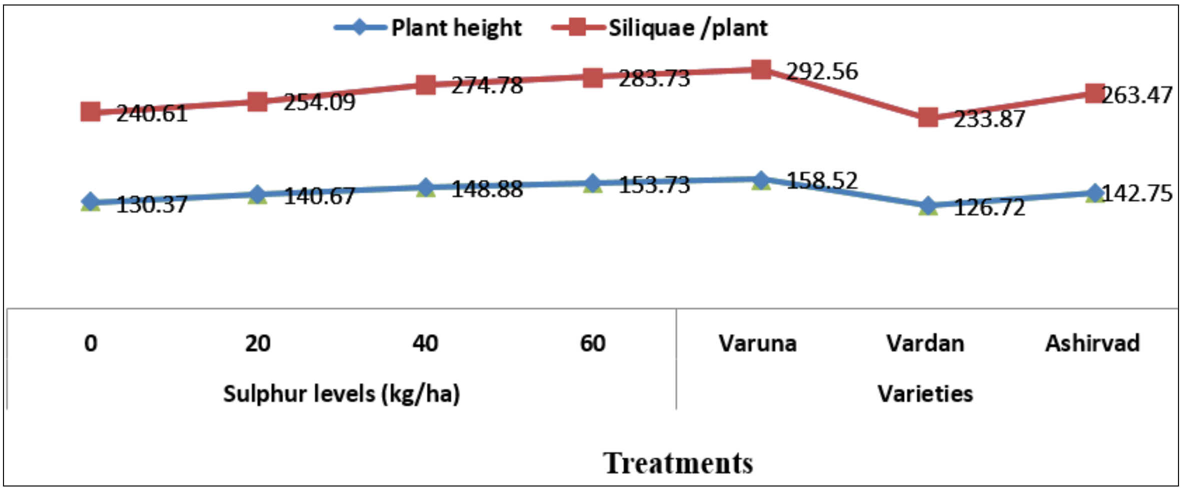

Fig 1: Impact of basal application of S on biometrical parameters of Indian mustard

Oil content: Oil content increased with increasing levels of sulphur and maximum oil content was recorded with application of 60 kg S ha^{-1} which was significantly higher over 20 kg S ha^{-1} and control at par with 40 kg S ha^{-1}. The maximum oil content (39.82%) was found in Varuan which was significantly higher over these of Vardan and Ashirwad. Non-significant interaction between sulphur levels and varieties in was obtained.

Table 1: Effect of sulphur levels and varieties on protein content, oil content and oil yield

Treatments	Protein content (%)	Oil content (%)	Oil yield (kg/ha)
Sulphur levels (kg ha^{-1})			
0	20.17	37.31	6.27
20	20.48	38.45	7.12
40	20.91	38.93	7.54
60	21.25	39.35	7.81
SEm±	0.46	0.66	0.41
CD (P=0.05)	NS	1.97	1.23
Varieties			
Varuna	19.30	39.82	7.68
Vardan	22.90	38.18	6.73
Ashirwad	19.91	38.24	6.92
SEm±	0.40	0.92	0.35
CD (P= 0.05)	1.18	NS	NS
S × V	NS	NS	NS

Interaction effect between sulphur levels and varieties of Indian mustard were found statistically non-significant in the protein content during year of investigation.

Oil yield: The data with respect to oil yield presented in Table 1 clearly indicate that, application of sulphur significantly increased the oil yield recording maximum oil yield 7.81 q ha^{-1} with 60 kg S ha^{-1} which remained at par with 40 kg S ha^{-1}. Varieties failed to produce significant differences in oil yield Varuna produced maximum oil yield of 7.68 q ha^{-1}, minimum oil yield o 6.73 q ha^{-1} recorded with produced significantly more oil yield over the variety Vardan and Ashirwad. The variety Varuna produced non significantly oil yield over the variety Vardan. Interaction effect between sulphur levels and varieties of mustard was found not statistically significant.

Basal application of different levels S affecting seed as well as stover yield and harvest index of Indian mustard

Seed yield (q ha^{-1}): The data presented in Table 2 clearly showed that seed yield increased significantly with increase in levels of sulphur. The maximum seed yield of 18.89 qha^{-1} was obtained at highest dose of sulphur which showed an increase of 20.03, 1.08 and 0.33 qha^{-1} over that of 0, 20 and 40 kg S ha^{-1}, respectively. The highest seed yield (20.51 q ha^{-1}) was obtained from Varuna against minimum seed yield (16.40) observed from Vardan, registering significantly higher 2.05 and 2.07 qha^{-1} over than Varuna and Ashirwad, respectively. However, the seed yield of Varuna variety was significantly higher over seed yield of Vardan.

Stover yield: The data with respect to stover yield presented in Table 2 revealed that stover yield increased with increasing levels of sulphur. The highest stover yield (68.66 qha^{-1}) was obtained at with application of 60 kg S ha^{-1} which was 10.43, 5.17 and 2.16 q ha^{-1} sulphur. Higher than those of 0, 20 of 40 kg S ha^{-1}, respectively. Varuna produced significantly higher stover yield of 70.80 qha^{-1} which was 7.16 and 14.2 q ha^{-1} higher than that Ashirwad and Vardan, respectively. The Interaction effect between sulphur and variety was non-significant.

Harvest index (%): A perusal of the data furnished in table 2 indicates that, harvest index was not influenced significantly neither by sulphur levels nor by varieties and their interaction.

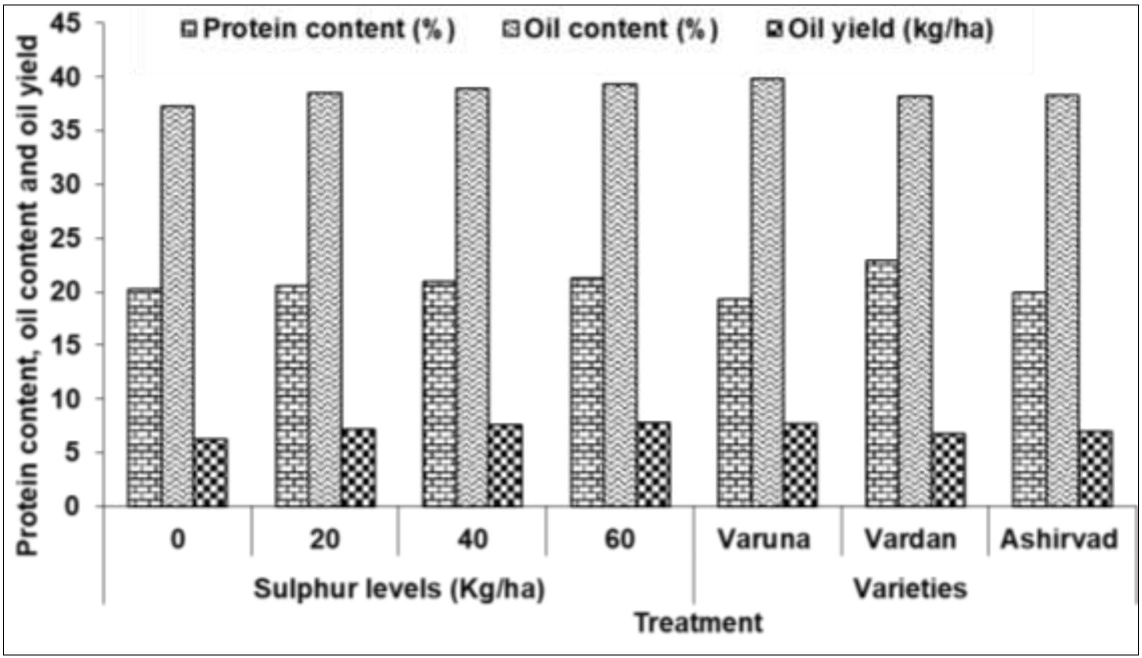

Fig 2: Effect of sulphur levels and varieties on protein content, oil content and oil yield

Table 3: Effect of sulphur levels and variety on sulphur content in seed, stover and total uptake of mustard

Treatments	Sulphur content by seed (%)	Sulphur content by stover (%)	Sulphur uptake (kgha^{-1})
Sulphur levels (kg ha^{-1})			
0	0.65	0.16	20.29
20	0.70	0.19	24.52
40	0.72	0.21	27.32
60	0.73	0.23	29.67
SEm±	0.01	0.02	0.53
CD (P=0.05)	0.03	0.05	1.55
Varieties			
Varuna	0.71	0.21	29.42
Vardan	0.69	0.19	22.23
Ashirwad	0.70	0.20	25.13
SEm±	0.009	0.02	0.46
CD (P= 0.05)	NS	NS	1.34
S × V	NS	NS	NS

Basal application of different levels S concentrations and their uptake in Indian mustard

Sulphur content in seed (%)

Data presented in Table 3 clearly indicated that sulphur content in seed increased with increasing levels of sulphur and maximum sulphur content was recorded with application of 60 kg S ha^{-1} which was significantly higher over 20 kg S ha^{-1} and control and at par with 40 kg S ha^{-1}. The maximum sulphur content (0.71%) was found in Varuna which was significantly higher over those of Vardan and Ashirwad. Interaction effect on sulphur uptake by seed was found to be non-significant.

Sulphur content in stover (%)

A cursory glance over the data presented in Table 3 clearly indicates that, sulphur content in stover increased with increasing levels of sulphur and maximum sulphur content was recorded with application of 60 kg S ha^{-1} which was 0.7, 0.4 and 0.2 per cent higher over that of 0, 20 and 40 kg S ha^{-1}, respectively. The highest sulphur content by stover (0.21) was obtained from Varuna against minimum sulphur content by stover (0.19) observed from Vardan registering significantly higher sulphur content over that of Vardan and Ashirwad. Interaction effect of various treatment on uptake of sulphur by stover was found non-significant during the year of investigation.

Uptake of sulphur by the crop (kg ha^{-1})

Data pertaining to the sulphur uptake have been presented in Table 3 the clearly indicated that uptake of sulphur increased with increasing level of sulphur. Sulphur uptake of 29.52 kg ha^{-1} recorded with 60 kg S ha^{-1} which was higher than all the levels, recorded higher S uptake of Varuna 29.42 kg S ha^{-1}. Which was significantly higher by 2.9 and 7.9 kg S ha^{-1} over that of Vardan and Ashirwad, respectively. Interaction effect on total uptake of sulphur and varieties was found non-significant.

Basal application of different levels S affecting efficiency indices and economic outcomes of Indian mustard

On the basis of net profit, the highest net profit (Rs. 23895) was found at combination of 40 kg S ha^{-1} with Varuna variety followed by Rs 23477 at a combination of 60 kg S ha^{-1} with Varuna variety. On the basis of net profit 3rd and 4th ranks were obtained with a combination of 20 kg S ha^{-1} and 60 kg S ha^{-1} with Vardan and Ashirwad, respectively. Whereas the minimum net profit (Rs 11239) was obtained at a combination of no application of sulphur with Vardan followed by combination with Ashirwad and Varuna, respectively.

On the benefit: cost ratio the highest net profit per rupee invested was (1.10 rupee) obtained at a combination of 40 kg S ha^{-1} along with Varuna variety. Whereas, the lowest net profit per rupee investment was (0.59 rupee) found at a combination of variety Vardan along with 0 kg S ha^{-1}.

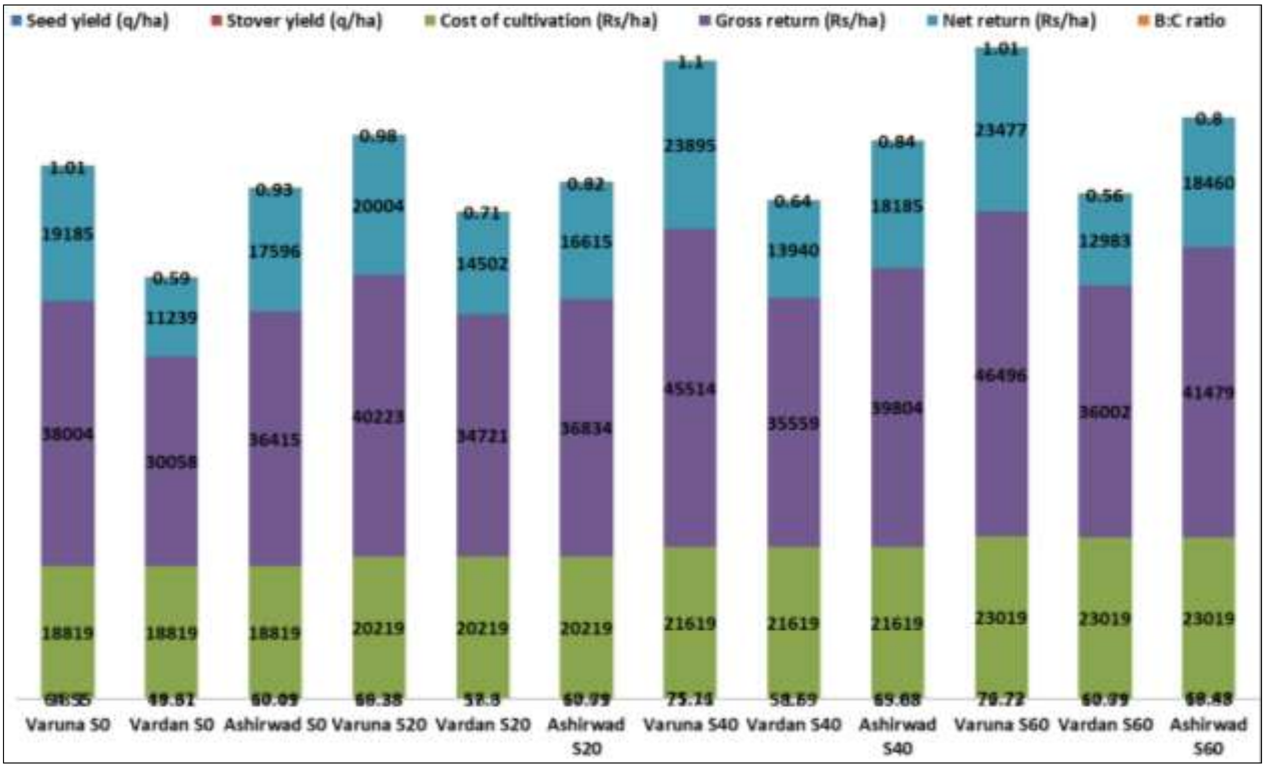

Fig 3: Economic of various treatment combinations in mustard

Discussion

Basal application of different levels S affecting some quality and growth parameters of Indian mustar

The higher oil content in seed was recorded with the application of 60 kg S ha^{-1}, which was significantly superior over control and at par with 40 kg S ha^{-1}. This was probably due to the facts that the sulphur is a constituent of lipids and it is also essential for the synthesis of lipids. Therefore, higher levels of sulphur increased the oil content in mustard. Similar results were also obtained by Issa and Sharma (2006) [12], Kumar *et al.* (2006) [12] and Singh *et al.* (2010) [31].

Protein content was not influenced significantly by sulphur fertilization though there was an increase of 1% with sulphur application. It could be due to higher nitrogen utilization by crop plants under adequate supply of sulphur, which enhanced the protein synthesis in plants and ultimately increased the protein content in seeds of mustard since sulphur is also a constituent of amino acids. Sulphur also provides disulphide (-S-S) bond for cross linkage in to two polypeptides chain and it helps in formation of protein. The increase in protein content with sulphur application was also reported by Singh and Meena (2003) [17].

Oil and protein content was greatly influenced by the varieties. The protein content of Vardan was significantly higher over Ashirwad and Varuna and later two varieties remained at par. The maximum oil content was found in Varuna which was significantly higher over those of Vardan and Ashirwad. This rise may be due to genetic characters of various varieties. Singh *et al.* (2010) [31] also reported that Varuna was found superior in oil content as well as protein content which was significantly superior than Vardan and NRCHB-101.

Basal application of different levels S affecting seed as well as stover yield of Indian Mustard

The variation in biological yield, seed yield and stover yield are the results of variation in various growth and yield contributing characters and hence productivity of mustard is collectively determined by vigourness in the vegetative growth and increase in value of various yield attributes. The higher number of siliqua plant^{-1}, length of siliqua, number of seed siliqua^{-1} and 1000-seed weight resulted into higher seed yield of mustard. The biological yield, seed yield and stover yield of mustard were significantly increased with increasing dose of sulphur upto 40 kg S ha^{-1} which was at par with 60 kg S ha^{-1} and significantly superior over control and 20 kg S ha^{-1}. The increase in seed yield under adequate sulphur supply might be ascribed mainly due to the combined effect of higher number of siliqua plant^{-1}, more number of seeds siliqua^{-1} and higher 1000-seed weight, which was result of better translocation of photosynthates from source to sink. Sulphur also stimulates the seed setting seed formation and oil synthesis in the seed of mustard and it increases the biological, seed, stover yield and harvest index of mustard. Rana *et al.* (2005) [23] and Dongarkar *et al.* (2005) [9] also reported the similar results.

Seed and stover yield increased significantly with increasing in evels of sulphur. The maximum seed and stover yield was obtained at highest dose of 60 kg ha^{-1} sulphur significant increase over unfertilized control. Similar results have been also obtained by Chandel *et al.* (2002) [5].

Yield is the result of co-ordinated inter play of growth and development traits. Cumulative response of growth and yield attributes to determine the yield. Seed and stover yield were highly responded to varieties. The maximum seed and stover yield were recorded in Varuna and it was mainly due to enhanced rate of photosynthesis and carbohydrate metabolism. The higher stover yield and harvest index was due to difference in varieties that is better partitioning of photosynthates towards seed leading to more seed yield *vis-a-vis* harvest index. The varietal differences in Indian mustard with respect to seed and stover yield and harvest index were also observed by Yadav *et al.* (2010) [39] and Singh *et al.* (2010) [31] reported that among Indian mustard varieties Ashirwad and Varuna gave significantly higher seed yield.

Basal application of different levels S affecting concentrations and their uptake in Indian mustard

Increasing levels of sulphur significantly increased the sulphur uptake over control. Significantly highest uptake of total 29.57 kg ha^{-1} sulphur was recorded with 60 kg S ha^{-1}. It might be due to crucial role of sulphur in chlorophyll and ATP formation, Fe-5 protein in photosynthesis and ferodoxin synthesis. Similar result have been also found by Panda *et al.* (2000) [22], Ghadge *et al.* (2005a) [10] and Singh *et al.* (2010) [31].

Effciency indices and economic analysis of Indian mustard

The highest net income was obtained at 40 kg S ha^{-1} with Varuna variety followed by 60 kg S ha^{-1} with Varuna. The highest net return per rupee investment were obtained at 40 kg S ha^{-1} with Varuna followed by 60 kg S ha^{-1} with Varuna. The variation in cost of cultivation was recorded due to variation in sulphur doses. Similar results have been also found by Virender *et al.* (2008) [36].

Conclusions

Thus it may be concluded than for obtaining maximum seed yield, oil yield and net return, Varuna variety of mustard fertilized with 40 kg S ha^{-1} may be adopted.

Conflict of interest statement

The authors declare no conflict of interest.

Author contributions

Pradeep kumar: Data curation; formal analysis; investigation; methodology; software; writing-original draft;writing-review and editing. Rajeev Kumar: Conceptualization; project administration; supervision. Anand Kumar Jain: Writing-review and editing.

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