Research Findings

Mustard field. Photo by IPI.

Effects of Polyhalite as a Fertilizer on Yield and Quality of the Oilseed Crops Mustard and Sesame

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Abstract

Mustard (*Brassica juncea)* and sesame (*Sesamum indicum* L.) are important oilseed crops in India. Both crops may benefit from sulfur (S) application. Polysulphate™ is the trade mark of the natural mineral 'polyhalite', which consists of four key plant nutrients - sulfur (S), potassium (K), magnesium (Mg), and calcium (Ca). In the present study, the effects of basal application of Polysulphate on the performance of mustard and sesame crops were examined in two distinct experiments. Each experiment included six fertilization treatments: T_1 - recommended doses of nitrogen (N) and phosphorus (P) (K omitted); T_2 - recommended NPK dose as control; T_3-T_5 - recommended NP + Polysulphate application at 20, 30, and 40 kg ha^{-1}, respectively, with compensation to the recommended K level; and, T_6 - recommended NPK + gypsum (with S dose equivalent to T_5). Potassium shortage reduced mustard and sesame grain yield by 12 and 17%, respectively, as compared to the control. In both crops, basal S application

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through Polysulphate brought about significant gains in grain yields with a linear response to the S dose, up to about 33% more at 40 kg S ha^{-1}, as compared to the control. Sulfur application appeared to increase the whole plant biomass, affecting most yield parameters, including oil concentration. Thus, mustard and sesame oil yields increased to 1,095 and 505 kg ha^{-1}, 39% and 43% more than the control, respectively. Sulfur application significantly increased K uptake by the plants, indicating a synergistic relationship between the two elements. Furthermore, S and K are translocated to the grains and are possibly involved in oil biosynthesis. It is concluded that S application at a macro-element dosage level significantly increases yields of oilseed species, such as mustard and sesame. The advantages of Polysulphate over gypsum as a basal fertilizer are discussed.

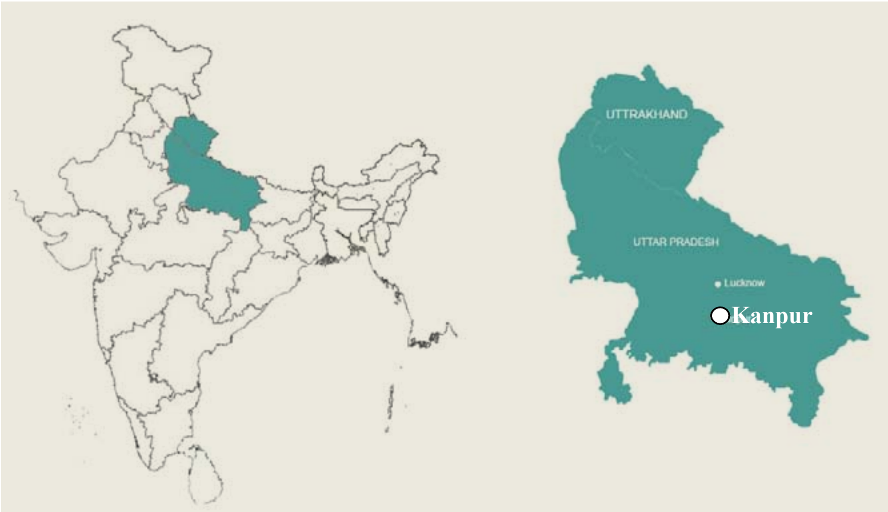
Photo 1. Polyhalite crystals. Photo by ICL Fertilizers.

Introduction

Human diets are changing and are becoming more reliant of vegetable oils. India is one of the major producers of many oilseed crops including groundnut, mustard, rapeseed, sesame seed, etc. Traditionally, Indians consume substantial quantities of edible oils that are mainly used for cooking. Among the oilseed crops in India, sesame (*Sesamum indicum* L.) is one of the earliest known crop based oils.. It contains 50% oil and 25% protein, as well as vitamins, minerals and antioxidants, and is grown across 1.74 million ha with a productivity of 421 kg ha^{-1} (OAS, 2009). The proteins in sesame seeds are remarkable for being rich in methionine, lysine, and tryptophan (Anilakumar *et al.*, 2010). These amino acids are essential for human nutrition, but are missing from a number of other vegetable protein sources, such as soy or cereals (Brosnan and Brosnan, 2006; Fukagawa, 2006). While significant efforts are being made to enrich various staple food crops with essential amino acids (Ufaz and Galili, 2008), sesame meal or flour can be used to enrich and provide a better nutritional balance to health food products (Prakash, 1985; El-Adawy, 1997; El-Adawy and Mansour, 2000; Quasem *et al.*, 2009). Methionine, a fundamental brick in protein biosynthesis, and cysteine, are both sulfur-containing amino acids, hence the availability of S is essential for normal growth and development of sesame plants. Furthermore, S-containing compounds contribute significantly to the aroma in heat-treated sesame seed oil and sesame butter (tahine) (Park *et al.*, 1995). Indeed, many studies have demonstrated the beneficial effects of supplemental S fertilization on crop growth and yield attributes in sesame (Rahul and Paliwal, 1987; Ghosh *et al.*, 1997; Tiwari *et al.*, 2000; Saren *et al.*, 2005; Puste *et al.*, 2015).

Sulfur is often associated with crops belonging to the Brassicaceae family that may possess significant amounts of S-containing secondary metabolites with various beneficiaries to plant protection, as well as to human health and diet (Stoewsand, 1995; Björkman *et al.*, 2011). The Brassicaceae include several oilseed crops, among which canola (rapeseed, *Brassica napus*) and mustard (*Brassica juncea*) are the most important ones economically. Mustard oil was once popular as cooking oil in northern India and Pakistan and is still the chief ingredient used in Bengali cuisine in Eastern India and Bangladesh. In the second half of the 20th century, the popularity of mustard oil declined in northern India and Pakistan due to the availability of mass-produced vegetable oils, but is still intricately embedded in the culture of the region. Sulfur and nitrogen (N) fertilization, and the balance between them, have a prominent effect on glucosinolate concentration in brassicaceous plants and an increased S supply has been shown to result in higher levels of total glucosinolates (Li *et al.*, 2007). Sulfur deficiency was shown to increase the disease susceptibility of canola to various fungal pathogens (Dubuis *et al.*, 2005) and this loss of antifungal activity was strongly correlated with the reduction of various glucosinolates, suggesting that they could have antimicrobial potential. An increase in S fertilization has also been shown to affect the content of polyphenols, such as flavonoids and phenolic acids (De Pascale *et al.*, 2007).

According to Khan *et al.* (2005), S is increasingly being recognized as the fourth major plant nutrient after N, P, and K. It is a constituent of amino acids cysteine and methionine, which act as a precursor for the synthesis of all other compounds containing reduced S (Marschner, 1995). Mustard (*Brassica juncea* L.) has the highest S requirement among various oilseed crops (McGrath and Zhao, 1996), but the amount required is not met due to the predominant use of N-based fertilizers (Zhao *et al.*, 1993). Thus, the shortage in S supplied to the crop lowers the use of other nutrients, particularly N. Several studies have established regulatory interactions between N and S assimilation in plants (Kopriva *et al.*, 2002). Sulfur availability regulates N utilization efficiency in plants, and thus affects photosynthesis, growth, and dry mass accumulation of crops.



Map 1. Map of Uttar Pradesh State in India (left), and the location of Kanpur city (right), where the experimental work took place. *Source*: http://office.incometaxindia.gov.in/kanpur/Pages/default.aspx.

Sulfur is readily available to plants only in sulfate (SO_4^{2-}), its inorganic form. Organic and elemental S must be converted to the inorganic form through microbial activity, a process depending on soil C:S ratio, temperature, and moisture (Boswell and Friesen, 1993). Sulfate may be applied as a fluid fertilizer (e.g. ammonium thiosulfate, 12-0-0+26S) through fertigation, although equipment and infrastructure required for this mode of application is seldom accessible or cost-effective. Calcium sulfate (gypsum) is an effective sulfur source, but not popular as a sulfur fertilizer because of its low sulfur content (15-18%). Other sulfur sources include fertilizers listed in combination with N, P, or K. Nitrogen-S materials include ammonium sulfate (21-0-0+24S), ammonium nitrate sulfate (30-0-0+15S), ammonium phosphate sulfate (13-39-0+7S), and ammonium phosphate nitrate (27-12-0+4.5S). Potassium-sulfur fertilizers include potassium sulfate (0-0-50+18S) and potassium magnesium sulfate (0-0-22+22S). Sulfate, as a negatively charged ion, is extremely mobile in the soil and is often leached from the root zone. Therefore, significant efforts are made to slow the release rate of sulfate to the soil (e.g. granulation), thus increasing energy inputs and product costs.

Polysulphate (Cleveland Potash Ltd., UK) is the trade mark of the natural mineral 'polyhalite' (Photo 1). Polyhalite occurs in sedimentary marine evaporates, consisting of a hydrated sulfate of K, Ca and Mg with the formula: $K_2Ca_2Mg(SO_4)_4 \cdot 2(H_2O)$. The deposits found in Yorkshire in the UK typically consist of K_2O: 14%, SO_3: 48%, MgO: 6%, CaO: 17%. As a fertilizer providing four key plant nutrients - S, K, Mg, and Ca - Polyhalite may offer attractive solutions to crop nutrition.

The objective of the present study was to evaluate effects and benefits of Polysulphate application in mustard and sesame crops under field conditions in Uttar Pradesh, India.

Two field experiments (mustard and sesame) were carried out on sandy loam soil at Oil Seed Farm Kalyanpur, C.S. Azad University of Agriculture and Technology Kanpur, Uttar Pradesh (India) during 2013-2014. Sub-surface (0-15 cm) soil samples were randomly collected before launching the experiment, and analyzed for their physico-chemical properties (Table 1).

Table 1. Major physico-chemical soil properties of the mustard and sesame experimental fields near Kanpur, Uttar Pradesh, India.

Properties	Mustard	Sesame
pH (1:2.5)	7.4	7.69
EC (1:2.5)	0.44	0.44
Available N (kg ha^{-1})	180	181
Available P (P_2O_5) (kg ha^{-1})	27.5	14.22
Available K (K_2O) (kg ha^{-1})	204	198
$CaCO_3$ (%)	1.2	1.21
Available S (kg ha^{-1})	16.8	16.6
Sand (%)	53.5	53.6
Silt (%)	22.5	22.2
Clay (%)	24	24.2

Mustard (var. Varuna) was sown on 11 November 2013, and harvested on 22 March 2014. Sesame (var. T-78) was sown on 20 July 2014, and harvested on 19 October 2014.

A similar experimental set was employed in both experiments: six treatments (T_1-T_6) were replicated three times in a randomized block design using 50 m^2 plots. Recommended doses of NPK and S were applied as per treatments. Full dose of P, K, S and half dose of N were applied at the time of sowing as a basal application. The remaining half dose of N was applied in two equal splits, at the stages of maximum tillering and flowering initiation. In treatments T_3-T_5, S and K were supplied through Polysulphate, and the required K dose was compensated with MOP. All agronomic practices and irrigation were carried out uniformly from time to time in each treatment. Further details are given in Table 2.

Table 2. Fertilization treatments included in the mustard and sesame experiments.

Treatment		N	P	K	S	Source of fertilizer
		-------------*kg ha^{-1}*-------------				
T_1	NP 100%	120	60	0	0	Urea and DAP
T_2	NPK 100% (control)	120	60	60	0	Urea, DAP, and MOP
T_3	NPK 100% + S 50%	120	60	60	20	Urea, DAP, MOP, and Polysulphate
T_4	NPK 100% + S 75%	120	60	60	30	Urea, DAP, MOP, and Polysulphate
T_5	NPK 100% + S 100%	120	60	60	40	Urea, DAP, MOP, and Polysulphate
T_6	NPK 100% + S 100%	120	60	60	40	Urea, DAP, MOP, and gypsum

Table 3. Effects of K deficiency (T_1) and of an increasing S dose through Polysulphate (T_3-T_5), or through gypsum (T_6), on the grain and stover yields of mustard and sesame. The harvest index (HI) presents the calculated ratio between the grain and the whole above ground plant biomasses.

Treatment	Mustard			Sesame		
	Yield		HI	Yield		HI
	Grains	Stover		Grains	Stover	
	----------*Mg ha^{-1}*----------			----------*Mg ha^{-1}*----------		
T_1	1.65	4.455	0.27	0.695	1.350	0.34
T_2	1.87	4.940	0.27	0.835	1.575	0.35
T_3	2.19	5.896	0.27	0.890	1.755	0.34
T_4	2.38	6.188	0.28	1.050	2.040	0.34
T_5	2.52	6.804	0.27	1.110	2.250	0.33
T_6	2.47	6.670	0.27	1.075	2.050	0.34
CD (P=0.05)	0.019	0.018		0.045	0.140	

Close to harvest, five plants of each plot were sampled, and yield properties (pods per plant, pod length, grains per pod, and weight of 1,000 grains) were determined. At harvest, grain and stover yield were determined for each plot, and the harvest index (grains to above-ground biomass ratio) was calculated. Oil was extracted by Soxhlet's method using petroleum ether as an extractant (Sawicka-Kapuskta, 1975) to determine oil concentration and yield. In mustard, S and K concentrations in the grains were determined on a fresh weight basis by digesting the samples in di-acid mixture of HNO_3 and $HClO_4$ (3:1). The digested samples were analyzed for K using a flame photometer (Jackson, 1967). S concentration was determined in the same extract by the turbidity method, as described by Chesnin and Yien (1951).

Results and discussion

In both mustard and sesame, grain and stover yields significantly declined by 12% and 17%, respectively, in the absence of K fertilization, compared to the control treatment (T_2) with the full NPK dose (Table 3; Fig. 1). The value of K fertilization in mustard has been recently demonstrated (Mozaffari *et al.*, 2012) and confirmed in the present study. However, the contribution of K fertilization to sesame cropping has been found insignificant in some previous studies (El-Aman *et al.*, 1998; Shehu, 2014). The results of the present study indicate an opposite situation or at least suggest considerable dependence on local edaphic conditions.

Yields of both crops rose significantly and steadily in response to the increasing S dose applied through Polysulphate in treatments T_3-T_5 (Table 3; Fig. 1). Mustard grain yield increased by 35%, from 1.87 Mg ha^{-1} at zero S application (T_2) to 2.52 Mg ha^{-1} at the maximum S dose, 40 kg ha^{-1} (T_5), applied with Polysulphate. A similar response was observed with sesame; grain yield increased by 33% at the maximum S level,

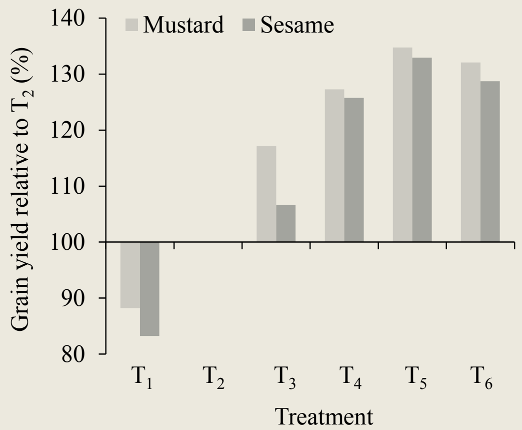


Fig. 1. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively) or through gypsum (40 kg S ha^{-1}, T_6) on the grain yields of mustard and sesame relative to fertilization with the recommended doses of NPK (T_2). For further details, see the materials and method section and Table 2.

Photos 2. Polysulphate fertilizer in granular (left) and standard (right) grades. Photos by ICL Fertilizers.

1.11 Mg ha^{-1}, as compared to 0.835 in the control. The same S dose, when applied through gypsum (T_6), yielded slightly fewer grains, significantly at least for mustard (Table 3; Fig. 1).

These results are in agreement with an expanding list of evidence demonstrating the crucial role of S in oilseed crops (Boswell *et al.*, 1993; Zhao *et al.*, 1993; McGrath and Zhao, 1996; Ghosh *et al.*, 1997; Tiwari *et al.*, 2000; Saren *et al.*, 2005; Puste *et al.*, 2015), leading to the statement by Khan *et al.*, (2005) that S should be considered as the fourth macro-element required for plant growth and development.

The different fertilization treatments did not affect the harvest index (HI, Table 3); it was very stable at 0.27 and 0.34, for mustard and sesame, respectively. In other words, the remarkable effect on the yields was not an outcome of any shift in dry matter allocation between vegetative and reproductive organs. Instead, the whole plant biomass responded by further growth and development, manifested in pod number and size, as well as grain number and weight (Table 4). Oil concentration in mustard grains increased from 41.85% to 43.45%, and in sesame from 42.2% to 45.5%. In both cases, however, oil concentration was significantly lower with K and S deficiency (Table 4). Under the recommended NPK fertilization practice (T_2), oil yields were 786 and 352 kg ha^{-1}, for mustard and sesame, respectively. When K was not applied (T_1), oil yields declined by 12% in mustard and 22% in sesame crops (Fig. 2). The response of oil yields to Polysulphate application was dramatic (Fig. 2) providing 39% and 43% increases (T_5 vs. T_2) to more than 1,095 and 505 kg oil ha^{-1} for mustard and sesame, respectively. Sulfur applied through gypsum (T_6) also gave rise to a significant increase in oil yields, although to a lesser extent than with Polysulphate.

Mustard grains accumulate significant amounts of S and K, 10 kg ha^{-1} and 13.5 kg ha^{-1}, respectively, even when the application of these two nutrients is actually suspended (Fig. 3, T_1). Potassium applied at the recommended dose (T_2) drew 4 kg K ha^{-1} more into the mustard grains, as well as additional S, although the latter was not applied here.

The special interaction between K and S with regard to their accumulation in mustard grains became obvious when S was applied. Unsurprisingly, S increased in grains proportionately to the applied doses, up to about 20 kg ha^{-1}. Unexpectedly, K - the

Table 4. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6), on major yield properties in mustard and sesame.

Treatment	Mustard					Sesame				
	Pods plant^{-1}	Pod length *(cm)*	Grains pod^{-1}	Grain wt *(g K^{-1})*	Oil *(%)*	Pods plant^{-1}	Pod length *(cm)*	Grains pod^{-1}	Grain wt *(g K^{-1})*	Oil *(%)*
T_1	195	4.4	9.8	4.85	41.85	97	2.8	43	3.1	39.5
T_2	197	5.1	9.9	5.05	42.02	105	2.9	47	3.4	42.2
T_3	202	5.8	10.2	5.35	42.45	115	3.0	48	3.6	43.5
T_4	204	6.2	11.8	5.36	42.22	125	3.1	58	3.8	44.2
T_5	204	6.2	11.8	5.36	43.45	130	3.2	60	4.0	45.5
T_6	201	6.0	11.7	5.35	42.14	120	3.1	50	3.7	43.9
CD (P=0.05)	1.84	0.26	0.36	0.04	0.51	4.7	-	3.2	0.12	1.1

Note: g K^{-1} = weight of 1,000 grains in grams.

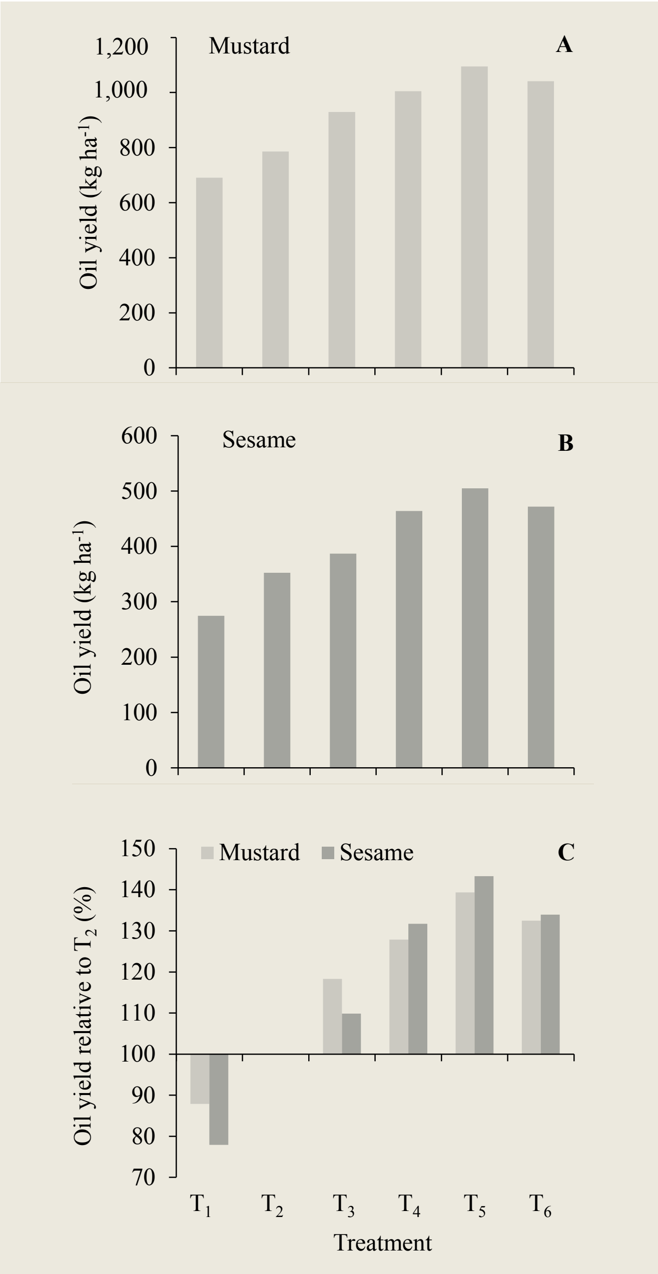


Fig. 2. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6), on the absolute oil yields of mustard (A) and sesame (B), and on their relative oil yields (C), as compared to T_2.

dosage of which remained fixed in T_2-T_6 - continued to accumulate in the grains at a constant K:S ratio of 1.37 (Fig. 3). This pattern could not be attributed, for instance, to better K availability from

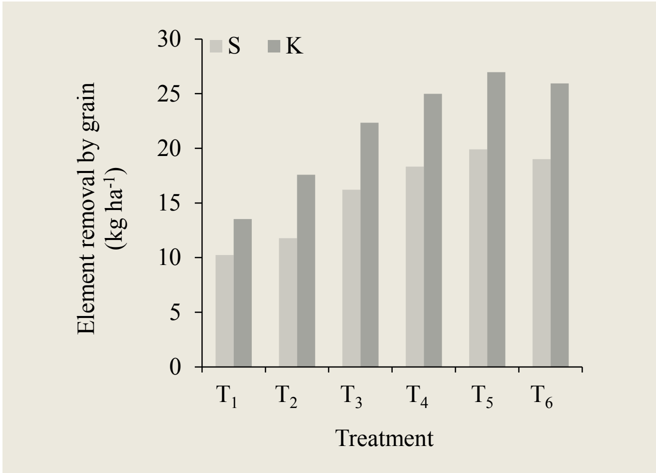


Fig. 3. Sulfur and K removal by mustard grains under K deficiency (T_1), recommended NPK dose (T_2), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6). For further details, see materials and method section and Table 2.

Polysulphate, as a similar phenomenon was observed when gypsum was the S source.

Under K deficiency and no S supplement (T_1), the reduction rate in K content in the grains was significantly greater than the reduction in S content in the grains and in the grain and oil yields. Compared to the control, K content in the grains declined by 24%, whereas S content, oil yield, and grain yield declined by 14%, 12%, and 11.5%, respectively (Fig. 4). Nevertheless, when S was applied, grain and oil yields increased proportionately at similar rates, whereas S content in the grains grew at twice the rate. Also, K accumulation in the grains grew 50% more than the increases in grains and oil yields. These results show that in mustard, S is translocated to the seeds together with significant amounts of K. In addition to their demonstrated contribution to yield increases, these two elements may have significant roles in the production of secondary metabolites (Stoewsand, 1995; Fukagawa, 2006; Li *et al.*, 2007; De Pascale *et al.*, 2007). N and S interactions have been demonstrated contributing to growth, yield, and quality of oilseed crops (Zhau *et al.*, 1993; McGrath *et al.*, 1996; Tiawri *et al.*, 2000; Kopriva *et al.*, 2002; Li *et al.*, 2007). The results of the present study strongly indicate the existence of a synergistic relationship between K and S that leads to improved yields and quality in mustard and sesame.

The present study demonstrates the worth of Polyhalite as an effective S source for plants. Its compactness, relative to gypsum, together with the considerable content of other significant

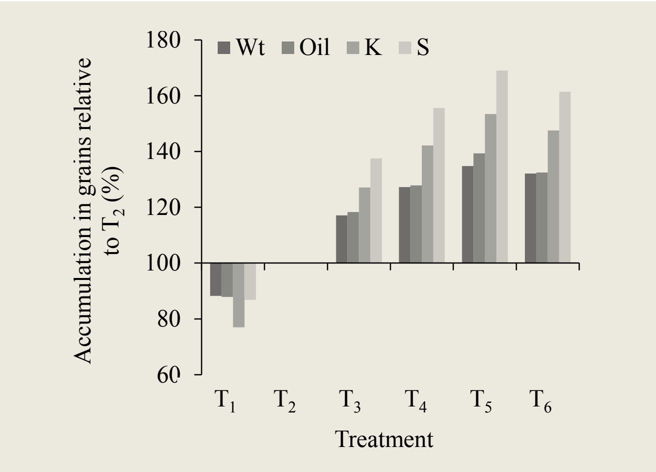


Fig. 4. Effects of K deficiency (T_1), S supplemented at 20, 30, and 40 kg ha^{-1} through Polysulphate application (T_3-T_5, respectively), or through gypsum (40 kg S ha^{-1}, T_6), on the accumulation of fresh weight, oil, K, and S in mustard grains, relative to fertilization with the recommended doses of NPK (T_2). For further details, see materials and method section and Table 2.

nutrients (K, Ca, and Mg) and the lack of Chloride, offer new solutions whenever basal S fertilization is taken into account.

Conclusions

- Potassium application is essential for obtaining reasonable grain and oil yields in mustard and sesame.
- Sulfur application at a macro-element dosage level significantly increases yields of oilseed species such as mustard and sesame.
- Sulfur and K seem to have a synergistic effect in oilseed species.
- Polysulphate is a considerable fertilizer for basal enrichment of soils with S, and also K.

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