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Role of Sulphur in cereals and oilseeds crops

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ABSTRACT

One of the most essential elements found in earth crust both in inorganic and organic form to be utilized by every living organism with average concentration of 0.06 % and presiding 13th position is Sulphur. Sulphur is also adjudged as the 4th important macronutrient amongst N, P, K to be taken up by both cereals and oilseeds crops in particular and acts as constituent for protein production and pivotal unit in chlorophyll, oil and vitamin synthesis in general. Indian soils are majorly deficient of N and Zn, with 41% of S deficiency which reduces the quality and quantity productivity of oilseed and other crops as it affects the uptake of available forms of N, P, K. Application of Sulphur containing fertilizers during growing period of crop enhances growth, yield, yield attributes, nutrient uptake and economic for several cereals and oilseed crops. The basic purpose of this review is to render upgraded researches related to sulphur comprehension in both oilseeds and cereals.

***Key words**: Sulphur, Cereals, Oilseed, Deficiency, Yield.*

Introduction

Sulphur is an inorganic element placed in group 16 and period 3 of the periodic table with atomic mass of 32.06 and atomic number 16. Sulphur is physiological essential nutrient for all living organism (Kopriva *et al*., 2015). Along with primary macronutrients S is also equalizing its importance (Jamal *et al.,* 2010. TSI, 2020). Application of S is somewhat tallying with amount of Phosphorus applied in certain crops. The major source of sulphur available for crop uptake is organic S. Mineralization of sulphur in soil is affected by weathering, organic matter and activity of microbes (Kumar, 2014). Area-wise sulphur deficit in Indian soils is recorded to be more than 41% (Singh, 2001). Sulphur removal from soil varies from 10-25 kg/ha for oilseeds whereas for pulses it is around 5-10 kg/ha pivoting on factors like crops grown, soil and environmental factors (Singh and Singh, 2016). The continuous use of S containing fertilizer in India, despite its higher cost has increased the ratio of N: P_2O_5: K_2O:S to 14:7.5:1.6: 1 (TSI, 2020). An inevitable operation of Photosynthesis in plants is possible owing to the fact that Sulphur is needed in chlorophyll synthesis which in turn produce starch, glucose, oils, fats, vitamins and other compounds in plants. It serves as base for protein synthesis being a part of S containing amino acids such as cysteine, cystine and methionine (Jamal *et al.,* 2010). It also acts as a constituent of vitamins, cofactors and various secondary products for several physiological activities (Luestek, 2000). According to TSI, 2020 sulphur increases the cereal quality for milling and baking, the marketability of dry coconut kernels, the quality of tobacco.

The nutritional value of forages etc. It acts a catalyst during several enzymatic reactions in plants. Cereals belonging to Gramineae family have comparatively more nutritional value, higher yield and serves as staple food in several countries around the world. Amongst Covid-19 pandemic too India had estimated production of 282.93 million metric tons of cereal in 2021 financial year. India after countries USA, China and Russia serves as world largest producer as well as exporter of several cereal crops.According to Zhao *et al.* (2001) requirement of sulphur for production of one ton of grains is about 1-6 kg, varies from 5-13 kg for legumes and 5- 20 kg for oilseed crops where deficiency of sulphur could reduce yield upto 50%. Accumulation of nitrates and arnides in soil reduces the protein synthesis and its quality in sulphur deficient soils (Gupta and Schnug, 2001). Estimating the increase in food demand to feed the burgeoning population would increase the S demand and its application for higher yield and quality. In lieu of projection of importance of sulphur in their crop physiology and economic yield in cereals and oilseeds this review has been summarized.

Sulphur Deficiency in cereals and oilseeds

Advancement in irrigation techniques, use of HYV seeds and increased fertilizer application has continuously depleted Sulphur from earth crust (Dutta *et al.,* 2013; Sinha *et al.,* 1995. Schrerer, 2001). Augment in application of high analysis sulphur free fertilizers (Chuabey, 1992) and scare input of organic manures (Sakal and Singh, 1997) has reduced S supply into soil. Decrease in use efficiency, economic yield as per NPK fertilizer application is drastically affected due to S deficiency (Khan *et al.,* 2006). Venkatesh and Satyanarayan, (1999) proved that 10 ppm is the critical available limits below which deficiency of S observed. Higher yield in wheat can be obtained by S concentration of 0.2 % and N:S of 18 during its flag leaf stage (Reneau *et al.,* 1986).

Basic deficiency symptoms in cereals crops are pale yellow or light green colouration of leaves. Even though symptoms of sulphur and nitrogen are similar in many ways, sulphur delays the maturity of in crops. In case of rice leaf sheath and blades turns yellow with stunted growth and reduction in number of panicles per plant. Younger leaves in maize show yellowing in between the veins but shows reddish colouration at base of leaves if deficiency continues to final stage of leaf margin. In wheat severe deficiency of Sulphur shows yellowing of whole plant whereas in case of sorghum initial deficiency causes younger leaves turn pale green while severe deficiency discolors the older leaves too.

Sulphur deficiency reduces economic yield and quality upto 40% in oilseeds (De Pascale *et al.*, 2008). Rapeseed are Sulphur sensitive crops yielding distinct deficiency symptoms (Zhao *et al.,* 1997). Accumulation of amino acids owing to deficiency of Sulphur lead to several disparities such as absorption and assimilation of nitrogen, shielding defense mechanism against stress. Coarse textured soil possesses lower sulphur content than fine textured soil. Takkar, (1988) revealed that sulphur deficiency in coarse textured soil might be due to lower content of organic matter. Available S is about 10% of total S in soil.

Sulphate form of S stored in older leaves are easily mobilized and transferred to the growing organs. Hence as deficiency occurs the young leaves remain small and pale green due to lack of protein and chlorophyll. Study by Schnug and Haneklaus, 2005 depicted the plant atrophy owing to the fact that S deficiency reduces cell division.

N:S widens as sulphur deficiency occurs causing accumulation of non-protein compound. Availability or deficiency of S in protein is basically adjourned by N:S ratio. Similarly, S:P ration lying within 0.9 -1.4 are duly considered as crop growth parameter (Abdin *et al.,* 2003).

Interaction of Sulphur with other nutrients

A parallel interaction was obtained between S and N in case of rapeseed and mustard (Sachdev and Dev, 1990). Negative effect was observed in case of groundnut and lentil with higher doses of P (Tiwari, 1990) whereas for groundnut K and S interaction was positive (Singh and Chaudhari, 1996). An antagonistic effect was observed for Mo with increased levels of sulphur (Guyette *et al.,* 1989). A synergistic effect of Fe and S was recorded with higher crop growth (Malewar and Ismail, 1997). Uptake of Selenium decrease with increased levels of S (Pezzarossa *et al.,* 1999). Both synergistic and antagonistic effect was observed with Zn and B. Concentration of Zn in groundnut is lowered with increase in S (Shukla and Prasad, 1979). Same trend followed for rice (Shah and De Dutta, 1991). Positive interaction of Zn and S was observed in mustard (Baudh and Prasad, 2012).

Physiology of sulphur nutrition in oilseeds

Mengel and Kirkby, 1987 described vividly the importance of S as a plant nutrient. S requirements in Plants are bridged by soil S, application of S containing fertilizers, irrigation water, pesticides having S etc. economic crop yield along with oil quality is increased with optimum availability of S for plant uptake. Oilseeds has S as both organic and inorganic compounds representing only 0.1 to 0.5 % by dry weight. Sulfate absorption is slightly lower than phosphate. S is absorbed mainly by plants from sulfate shaped roots, but it can also be absorbed by leaves in the form of SO_2 gas from atmosphere. After absorption the gas is transported to the endosperm where it is secreted in the xylem and transported to the leaf by the flow of perspiration. S is necessary for the synthesis of protein, oils, and vitamins. About 90 % of the reduced S is required for the protein because it is constitutive of methionine (21 %S), cysteine (26% S) and cystine (27% S). S is also a component of the S-glycosides in mustard oil, coenzyme A. the iron and sulfur protein centers serve as electron carriers.

Role of Sulphur in Oilseeds and Cereals

Yield improvement in oilseeds

Sulphur enhances yield and seed quality efficient of nitrogen and phosphorus in sunflower seeds. Synthesis of S containing amino acids, chlorophyll, biotin and thiamine, metabolism of carbohydrates, oil and protein content is affected directly or indirectly by availability of S as studied by Najar *et al.,* 2011. Increased yield of mustard seed has been reported by Kumar and Trivedi (2012). When availability of S increases, tissue differentiation from somatic meristematic to reproductive and developmental activity primordial flower could have grown, resulting in more floral siliqua, a longer siliqua and a higher seed yield. Maximum yield in mustard is obtained due to S application @ 30 to 60 kg/ha of S fertilizers (Fismes *et al.,* 2000).

The yield in case of rapeseed increased upto 3.96t/ha with application of 40 kg of S fertilizer was reported by Varenyiova *et al.* 2017. The oil content significantly increased upto 45.1, 45.5, and 44.0 percent with sulfur doses of 15, 40 and 65 kg/ha applied respectively. The similar result with improved quality attributes of protein and enzyme synthesis was corroborated by Kumar *et al.,* 2011. A pot experiment on flax crop for studying sulphur nutrition in yield and quality parameter at Kanpur was carried down by Minz *et al.,* 2017, where the results were as such, plant height (66.13 cm), no. of branches per plat (6.35), test weight and seed yield were 8.60 g and 14.33 g/pot respectively. The oil content increased by 4.35 percent from control with application of 60 ppm sulfur. At Allahabad Agricultural farm a study on mustard with sulfur interaction was carried out by Khatkar *et al.,* 2009, proving that plant attributes, yield, quality parameters improved with increased dioses of sulphur application.

Quality improvement in oilseeds

Ahmad *et al.,* 2000 from his study reported that application of Sulphur significantly increased the oil content by 15-30 percent in several oilseed crops like groundnut, rapeseed-mustard etc. He along with his co-worker Abdin in 2003 proved that sulfur application hastened the process of protein synthesis. Sulphur nutrition has also affected the composition of oil, acetyl-Coa and acetyl- COA carboxylase in oilseeds. Brennan *et al.,* 2000 studied that oil content in rapeseed has been directly affecting protein content, which was further enumerated by Krauze and Bowszys, 2000, with findings that protein content and oilseed might have an ambiguous relation in case of rabi mustard with sulphur application. Somania *et al.,* 1988 and Kumar *et al.,* 1981 revealed that S containing amino acid such as Cystine, methionine and cysteine were increased by increased doses of S application in rapeseed- mustard and soybean respectively. Studies by Wanasundara, 2011; Aachary and Thiyam, 2012 have proved that antioxidant, antidiabetic, anorectic, anticancer antiviral activities have been carried out by protein peptides in rapeseeds. A recent study by Longkumer et al., 2017 have illustrated that lone application of sulphur or in combination of Boron has improved oil content in Soybean, similar findings were revealed before by Devi *et al*., 2012 which showed improved yield attributes, yield, oil and protein content, etc.

Role of sulphur on growth and yield of cereals.

As reported by Naw Mar Lar *et al*., 2007, the yield attributes like plant height, effective tillers/hill, panicle length, test weight of grain of aromatic rice increased significantly with higher application S fertilizers i.e. 60 kg/ha also gave highest grain yield (5.54 tons/ha), straw yield (13.64 tons/ha), biological yield (19.17 tons/ha). According to a field experiment conducted on pearl millet by Sandeep Singh *et al.,* 2016, 2017, clarified that increased doses of Sulphur application @ 30 kg S/ha increased the plant height to 224.7cm, ear head length (29.1 cm), ear head diameter (10.85 cm) and test weight of 11 gm and the yield of grain and stover yield increased to 3.43 and 8.34 t/ha respectively. An experiment conducted on quality protein maize by Jeet *et al.,* 2014 reported that higher dose of S (45 kg/ha)than base levels rendered increased number of green leave / plant, dry matter, cobs/plant, cob diameter, and test weight. Similarly increased doses of S @ 45 kg/ha on maize provided significantly increased yield and yield attributes and influenced length of cob (16.7cm), 100-grain weight (32.4 g) and straw yield (14562 kg/ha) as conducted by Bharathi and Poongothai (2008). Application of S fertilizer is eventually beneficial for Sorghum yield has been experimented by Kumbari and Kubsad (2019) where yield and its attributes increased significantly. Thirupathi *et al.,* 2016, while experimenting on Maize found out that with increase doses of S upto 60 kg/ha increased the plant height, dry matter and leaf area index along with that grain and stover yield was also increased significantly. While experimenting on quality parameters of protein maize by Pavithra *et al.,* 2018 reported thatwith application of S @ 45kg/ha significantly increased plant height (162.9cm), leaf area index (1.83) and dry matter (8117) with respect to its control application of fertilizers with same dosage of S the grain yield obtained was 3679 kg/ha and stover yield was 4029 kg/ha with respect to 2997 kg/ha and 3390 kg/ha respectively with respect tocontrol.

S application upto 20kg/ha more on Boro rice as reported by Rahman *et al.,* 2007, had significantly increased yield and yield attributes. He reported that grain yield, straw yield and biological yield significantly increased to 5.81 t/ha, 7.38 t/ha and 13.19 t/ha respectively. Vikas *et al.,* 2017., noted that with application of 45 kg/ha S significantly increased plant height (105.13 cm), LAI (4.48) and dry matter accumulation (963.39 g/m^2) from 90 DAS to harvest. He also sited that yield and yield attributes like number of shoots (365.87/m^2), length of panicle (25.92 cm), number of grains/ panicle (192.93), test weight (23.10 g), grain yield (43.29 %).

Rice yield was improved with increase in S doses upto 30 kg/ha as reported Asha Ram *et al.,* 2016. He also reported that irrespective of source of S applied to aerobic rice maximum panicle weight (2.19 g) was obtained due to application of 60 kg/ha and highest grain per panicle (130). Rakesh Kumar *et al.,* 2014 sited that application of S in form of Phosphogypsum (3.09) and SSP (2.93) increased grain yield in rice from 2.52 to 2.92 t/ha. Harvendra Singh and Harendra Singh (2014) deduced their findings from experiment on pearl millet that application of 40 kg S/ha as ammonium sulphate resulted increased grain yield (23.08, 22.96 q/ha) and stover yield (55.81, 55.47 q/ha) as compared to control.They also conducted an experiment during 2013, sited application of S 2 25 kg/ha on wheat significantly increased its grain yield (46 q/ha) and straw yield (66.8 q/ha). Anil *et al.* (2012) conducted an experiment on rice with application of 30 kg S/ha reporting improved yield attributes like panicle/m2 (303.6), grain/panicle (204.9), grain yield 97.44 t/ ha), harvest index (0.42) and 1000 seed weight (15.9 g) as compared to control. Barley was used as test crop with application of several doses of Sby Manoj and Mranalini (2016) revealed that application of S @ 40 kg/ha significantly increased ear length (17.97 cm), grain yield (58.02 q/ha) and straw yield (137.12 q/ha) as compared control i.e. to 15.85 cm, 50.11 q/ ha and 116.79 q/ha respectively.

d) Effect of sulphur on nutrient uptake by cereals

In an experiment on rice Naw Mar Lar *et al.,* (2007) reported that there was a significant increase in N uptake over control with application of 20 kg/ha, 40 kg/ha and 60 kg/ha with N uptake as follows 12, 13.5 and 17.2 % respectively, similarly P and K uptake significantly increased in grain (8.4 kg/ha, 26.6 kg/ha) and straw (6.7 kg/ha, 88.4 kg/ha) with application of S @ 60 kg/ha. There was a significant increase in N (140.4, 134.3), P (19.3, 19.6) and K (29.8, 29.3) uptake when S was applied @ 25 kg/ha on wheat crop by Harvendra Singh and Harendra Singh (2013) for two consecutive years with that post harvest soil status for OC (5.18 g/kg), available N (264.7 kg/ha), available P (17.2 kg/ha) and available sulphur (14.3 mg/kg). In their another experiment with pearl millet (2014), they reported that application of S @ 60 kg/ha and as ammonium sulphate significantly improved N and P availability in post harvest soil. An experiment on pearl millet conducted by Sandeep Singh, 2017, explained that with application of S @ 30 kg/ha significantly improved N, P, K uptake having figures 57.2 kg/ha, 45.8 kg/ ha; 8.3 kg/ha, 10.8 kg/ha: 19.8 kg/ha, 170 kg/ha in grain and stover respectively whereas sulphur uptake increased significantly with application of S @ 60 kg/ha in both grain and stover. Application of S @ 40 kg/ha in barley increased organic carbon, available nitrogen, available phosphorus and available K upto 4.2 g/kg, 146.2 kg/ha, 9.4 kg/ha and 120.5 kg/ha in post harvest soil as compared to control as reported by Manoj and Mranalini, 2016. According to a report by Anil *et al.,* 2012, concentration of N, P and K 1.23, 0.52, 0.83 % in rice with S application @ 40 Kg S/ha. As per the report basing upon the experiment conducted on maize by Bharathi and Poongothai (2008) with increased levels of S the Uptake of N, P, K increased both in grain and straw. Grain and straw in case of barley showed increased uptake of N, P, K, S and Zn with application of S @ 40 kg/ha showing statistics of 115.6, 76.4 kg/ha; 13.4, 17.0 kg/ha; 29.3, 267.7kg/ha; 14.8, 20.1 kg/ha and 139.4, 245.8 g/ha respectively, was proved by Manoj and Mranalini, 2016. Sandeep Singh, 2016 reported significant increased. uptake of N (55.6, 45.0 kg/ha), P (8.3, 10.4 kg/ha), K (19.5, 165 kg/ha) and Zn (76.8, 239.8 Kg/ha)in grain and straw of pearl millet with application of S @ 30 kg/ha.

Effect of Sulphur on quality of cereals

Application of S @ 40 kg/ha in rice increased protein yield to 234 kg/ha as studied by Rakesh Kumar *et al.,* 2014, who also revealed that phosphogypsum yielded highest protein (207 kg/ha) as a source. Harvendra Singh and Harendra Singh, 2014 revealed that application of ammonium sulphate in pearl millet gave highest protein content (10.6 %), protein yield (235.4 kg/ha). Sandeep Singh, 2017 reported that application of 45 kg S/ha on pearl millet yielded highest protein in grain (10.6%). Crude protein content in maize was increased by 18.1%with application of S @ 60 kg/ha as revealed by Thirupathi *et al.* (2016). Discussing about the quality parameters in barley, Manoj and Mranalini ,2016 reported that application of S @ 40 kg/ha showed highest protein content (12.3), protein yield (722) and starch content (53.8).

Conclusion

Lower consumption of S containing fertilizer, unhealthy soil and large propagation deficit has reduced S availability for uptake by oilseed crops which has resulted in reduced yield and quality of oilseeds and cereals. Going by statistics the removal of S from soil by crops is about 1.26 Mt whereas its fertilizer replenishment is just around 0.76 Mt. Sulphur deficiency not only reduces the yield and quality but also reduces uptake of N, P, and K which later on disturbs entire plant physiology yielding less and dropping the economic. The sulphur requirement has to be met to render higher yield and other qualities which done by proper management of sulphur by using primary nutrients containing S such as ammonium sulfate, SSP, potassium sulfate etc., using S containing materials like phospogypsum, S elements, pyrite and iron sulfate to drag out Indian soils from S deficiency. The use of proper dosage of S not only increases yield but also improves the quality of oilseeds and cereals. As S has been emerging as the 4th most important macronutrient along with primary nutrients its judicious and efficient consumption is mandatory.

Conflict of Interest

The authors declare no conflict of interest.

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