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Research Article

Application of humic acid and foliar sulfur positively affect yield and related attributes of soybean under the agroclimatic region of Peshawar Pakistan

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Abstract

To address the challenges posed by declining sulfur deposition and exploring alternative fertilization strategies like foliar application, a trail was conducted to assess the effect of humic acid (HA) and foliar sulfur levels on soybean cultivars at The University of Agriculture Peshawar, Pakistan during spring season 2022. RCB design with three replications was employed. Four levels of HA (0, 3, 6 and 9 kg ha^{-1}), four FS levels (0, 4, 6, 8%) on two soybean cultivars (Malakand-96 and Parachinar) were tested. Findings showed that HA applied at 9 kg ha^{-1} hasten flower initiation (56) and delayed maturity (104), increase plant height (93.4 cm), branches plant^{-1} (12), leaves plant^{-1} (109), pods plant^{-1} (98), pod length (3.7 cm), seeds pod^{-1} (2.6), thousand seed weight (174.7 g), biological yield (12118 kg ha^{-1}), grain yield (3106 kg ha^{-1}), oil contents (21.0%) and protein content (32.07%). Similarly, FS applied at the level of 8% reduced days to 50% flowering (56) and maximized the days to 50% (103) maturity, plant height (94.0 cm), branches plant^{-1} (11), leaves plant^{-1} (109), pods plant^{-1} (99), pod length (3.6 cm), seeds pod^{-1} (2.5), thousand seed weight (173.1 g), biological yield (12116 kg ha^{-1}), grain yield (3090 kg ha^{-1}), oil content (21.0%) and seed protein (32.08%). Malakand-96 gave maximum thousand seed weight (172 g) biological yield (11533 kg ha^{-1}), grain yield (3042 kg ha^{-1}), oil contents (20.3%) and protein content (31.65%) while minimum yield and related components were associated with Parachinar cultivar. It is advised that cultivar Malakand-96 under treatment of HA at 9 kg ha^{-1} and FS at the level of 8% should be employed for improved soybean production.

Keywords: Delayed maturity; Malakand-96; Quality; Yield enhancement

Introduction

oybean (*Glycine max* L.), a member of (*Leguminosae*) family is a significant crop due to its wide geographical adaptability, distinctive bio-chemical makeup, high dietary value, functional health advantages, and wide range of (food-feed). It helps in increasing the fertility of the soil by fixing atmospheric nitrogen into ammonia varies in amount of 50 to 300 kg ha^{-1} which mostly differs on climatic circumstances crop diversity and strains etc. [1]. Soybean oil includes 40% high-quality protein and vital amino acids. It additionally includes a good source of antioxidants as well as fatty acids ofomega-3 and contains 23% carbohydrate, 20-24% fat (depending upon varieties) and a sufficient quantity of minerals, vitamins, and dietary fiber [2].

Humus is the final product of organic matter decomposed by microorganisms. Humic acid HA compounds include humus constituents that are widely spread throughout the earth's surface [3]. Humic compounds are categorized into three types: fulvic acid and humin. HA is a viable substance that comprises several functional groups along the carbon chain. They may be neutral groups, which promote plant development, such as alcohol, aldehyde, ketone, ether, ester, and amide, or they may be acidic or alkaline, such as acetic acid and phenol. Humic acid compound known as potassium humate is black in color, water soluble, but insoluble in alkalis [4]. Solange HA contains 51% -57% C, 4% -6% N, 0.2%-1% P, and small elements of other micronutrients. HA is a necessary component of the topsoil carbon-based (organic) building. It is believed that humic acid has been employed by researchers, farmers and agronomists to improve soil conditions and plant development and growth attributes. HA fertilization boosts photosynthetic efficiency by improving soil hydro-physical characteristics and nutrient accessibility [5]. It is reported that one kg of HA can be utilized in replacement of 1-ton of organic manure [6]. Humic acid is widely known because of its function in reducing soil-borne diseases and it can also enhance the soil health, uptake of nutrients by plants, availability of minerals, fruit quality and so many others [7]. The application of HA-based fertilizers can enhance crop yields, promote the activation of plant enzymes and hormones and as well as assist improve nutrients in the soil (fertility) in an environmentally sustainable and ecologically beneficial manner [8].

Sulfur is a vital macronutrient and the 4th chief plant nutrient next to N, P, and K [9]. Most crops require Sulfur because it is essential for the formation of chlorophyll and oil. Sulfur boosts the amount of glucosinolates in the seed [10] and is required in comparable levels to phosphorus and magnesium for soybean crop growth [11]. Sulfur contributes in the fatty acids synthesis and enhances protein quality over the formation of certain amino acids, as well as having particular functional roles in enzymes, vitamins, lipids and other essential plant components [12, 13]. Sulfur fertilization can affect several storage protein fractions in legumes (albumin, globulin, prolamin, and glutelin) [14]. Oilseed crops require more Sulfur than cereal crops since this element is essential for pod formation and a lack of it results in sterile pods. In general, an appropriate Sulfur supply increases yield significantly [15]. The main problem of sulfur in agriculture is the reduced industrial sulfur emissions globally that are diminishing sulfur deposition on agricultural land, impacting crop productivity and nutritional quality. This decline presents a challenge for effective sulfur fertilization in agriculture [16]. There is documented evidence of sulfur deficiencies in soybeans, along with observed responses to sulfur application in various soybean-producing regions in the United States [17, 18]. Consequently, ensuring adequate sulfur supplementation is deemed crucial for enhancing soybean yield and seed quality [19]. Sulfur fertilizers can be introduced into the soil. However, effective sulfur nutrient management faces challenges, due to the risk of sulfate leaching and time gap that exists between the application of the sulfur and their incorporation by the plant, leading to its loss and unavailability during critical periods of crop demand [20]. Applying fertilizer to the foliage presents an alternative to the traditional pre-plant soil sulfur application, catering to the crop's peak sulfur demand. Foliar fertilization, being target-oriented, allows for precise nutrient delivery at the right moment **[21]**. Considering the importance of humic acid and foliar Sulfur treatment on soybean productivity, a research was undertaken to determine the optimal combination of HA and FS for enhancing growth and yield of soybean cultivars in the agro climatic conditions of experimental area.

Materials and Methods

Experimental site and design

A field experiment entitled "Effect of humic acid and foliar Sulfur levels on soybean cultivars" was assessed at New Developmental Farms, The University of Agriculture Peshawar, Pakistan during *spring* season April 2022. The trial was carried out in RCB design having three replications. The individual size of plot was 1.8m x 4m with 4 rows having row-row distance of 45 cm. The experimental area was prepared by ploughing twice and then planking. Four irrigations were administered with the first one occurring 20 days after germination the second after 55 days during the flowering stage the third after 70 days during the pod filling stage and the fourth after 85 days during the seed development stage. Weeds were removed manually using a hoe. Uniform cultural and agronomic practices were performed throughout the entire growth period

Treatments and their levels

Four levels of soil applied humic acid (HA) (0, 3, 6 and 9 kg ha^{-1}) obtained from local market of sky seeds brand and four levels of foliar Sulfur FS i.e. (0, 4, 6 and 8%) in the form of Kamulus D-F (FMDC) solution at V5 stage were tested on two soybean cultivars (Malakand-96 and Parachinar). For zero percent FS application only water was applied. For making 4% solution 40 g of S was dissolved in 1000 ml of water. Similarly, for 6% and 8 % solution 60g & 80g of S were dissolved in 1000 ml of water respectively. Nitrogen, phosphorus and potassium fertilizer were applied from numerous sources i.e. urea, (SSP) and (MOP) at the rate of 25:60:50 (kg ha^{-1}) during preparation of seedbed. Two soybean cultivars were sown at the rate of 80 kg ha^{-1}. The experimental area was prepared by ploughing twice and then planking. Four irrigations were administered with the first one occurring 20 days after germination the second after 55 days during the flowering stage the third after 70 days during the pod filling stage and the fourth after 85 days during the seed development stage. Weeds were removed manually using a hoe. Uniform cultural and agronomic practices were performed throughout the entire growth period.

Data collection

Growth and yield related traits

Data collection encompassed various parameters to assess the growth and development of plants in the experiment. The duration up to 50% flowering and physiological maturity was recorded by noting the sowing date and counting the days until these stages were reached. Plant height was determined by measuring from the base to the top of five randomly selected plants in each plot, with the resulting data averaged across the entire plot. To ascertain branches plant^{-1}, branches per plant was counted for five randomly selected plants in each plot. Similarly, the leaves plant^{-1} was determined by counting leaves on five randomly chosen plants per experimental unit. Assessing reproductive metrics, the average pods plant^{-1} was calculated by counting pods on five randomly selected plants per plot. Pod length was measured from the top to the base of pods on five randomly chosen plants per plot. For seed-related parameters, the number of seeds pod^{-1} was determined by counting seeds in five randomly selected pods per experimental unit, and the thousand grains weight was measured by weighing a sample of 1000 seeds from each plot.

Biological and grain yield

For biological yield determination, the central four rows of each experimental unit were manually bundled, sun-dried, and weighed in the field to obtain the initial biological yield. Subsequently, this biological yield was converted to kg ha^{-1} using Eq.1. Grain yield was calculated from previously harvested two rows in each plot, with the samples dried, threshed, and weighed to obtain the grain yield (kg ha^{-1}) using Eq. 2.

$$\text{Biological yield} = \frac{\text{Biological yield in central two rows x 10000 m}^2}{\text{Number rows x row length x row−row distance}} \quad \text{(Eq. 1)}$$

$$\text{Grain yield} = \frac{\text{Grain weight of central two rows x 10000 m}^2}{\text{number of rows x row length x row−row distance}} \quad \text{(Eq. 2)}$$

Seed oil and protein content (%)

For the determination of crude oil content, two-gram seed were dried taken in a paper thimble attached to soxhlet extractor. 200 ml ether was taken in a flask and attached with extraction apparatus over a hot plate. Ether evaporated condensed and fall on sample drop form. Condenser filled with ether and fat in the siffen in to the flask, continuously for five hours. After five hours' ether were distilled either evaporated left in the flask through dry in oven at 70° to 80° degree centigrade for two hours. The flask was weighted using Eq.3 after cooling in a desiccator.

$$\text{Oil content \%} = \frac{\text{weight of flask with oil − weight of empty flask x 100}}{\text{weight of original sample}} \quad \text{(Eq. 3)}$$

Kjeldahl setup that involved digestion, distillation and titration was adopted for determination of seed protein content. Nitrogen percentage obtain in the process was multiplied by a constant of 6.25 to compute seed protein content [22].

Statistical analysis

The mentioned information was numerically examined utilizing study of variance strategies suitable for RCB designs. The *LSD* test at level (*0.05*) of chance stood utilized to match the means when the values of F are significant.

Results

Growth attributes of soybean

Data regarding growth attributes are presented in (Table 1). It was clear from the results that applying HA and FS had a positive effect of growth related traits of soybean cultivars. However, the interaction between HA, FS and cultivars was found to be not significant for all the studied traits. In response to HA fertilized at the amount of 9 kg ha^{-1}, less (56) days to flowering was noted while more days to flowering (60) were seen in control plots. In case of FS, its application at the level of 8% had minimum days to flowering (56) which was not significantly different from 6% (58) in comparison to more days recorded (59) in control plots. Among cultivars, Malakand-96 took least (56) days while Parachinar took highest (59) days reaching 50% flowering. Regarding days to 50% maturity of soybean in response to HA utilized at amount of 9 kg ha^{-1} took maximum (104) days in comparison to minimum (100) days to maturity noted in control plots. Plots fertilized with FS application of 8% had maximum days to maturity (103) whereas minimum (101) days to maturity were observed in control plots. Among the cultivars Malakand-96 took maximum (100) days to maturity while Parachinar took least days to maturity (102). According to results, plots where HA was employed at the concentration of 9 kg ha^{-1} had given long stature plants of (93.4 cm) followed by 6 kg ha^{-1} application of HA (91.8 cm). Lowest plant heights of (86.4 cm) were observed in control sections. Plots given with foliar Sulfur application of 8% had long stature plants of (94.0 cm) followed by 6% of (92.1 cm). Lowest plant height (86 cm) was documented in control plots. In case of cultivars, Malakand-96 had highest height of (91.6 cm) while minimum (89.1 cm) height was detected in

Parachinar. More branches plant^{-1} (12) were reported in plants fertilized with HA at amount of 9 kg ha^{-1} as followed by 6 kg ha^{-1} of (11) branches plant^{-1}. Lowest numbers of main branches plant^{-1} (9) was noted in control plot. The branches plant^{-1} was also boosted with the enhanced intensity of foliar Sulfur. An additional branch plant^{-1} (11) was examined in plants handled with 8% statistically similar to 6% of foliar Sulfur doses which resulted in (11) main branches plant^{-1}. Lowest quantities of main branches (9) were noticed in control plots. Both cultivars i.e. Malakand-96 and Parachinar produced same branches plant^{-1} (10). In response to HA at the proportion of 9 kg ha^{-1} soybean produced more (109) leaves in comparison to less (102) leaves plant^{-1} recorded in untreated plot. Among the FS, more number (109) of leaves plant^{-1} were counted in plots treated with 8% that was statistically similar to 6% of applied rate having (108) leaves plant $^{-1}$. Lower (102) leaves count was seen from control. Moreover, Malakand-96 produced more leaves (107) plant^{-1} while minimum was counted in Parachinar cultivar (105).

Table 1. Growth attributes of soybean cultivars as impacted by HA and FS application

Humic acid (kg ha^{-1})	Days to 50% flowering	Days to 50% maturity	Plant height (cm)	Branches plant^{-1}	Leaves plant^{-1}
0	60 c	100 d	86.4 d	9 c	102 d
3	58 bc	102 c	89.9 c	10 b	105 c
6	57 b	103 b	91.8 b	11 b	107 b
9	56 a	104 a	93.4 a	12 a	109 a
LSD *(P≤ 0.05)*	0.61	0.60		0.23	0.69
Foliar sulfur (%)					
0	59 c	101 d	86.4 d	9 c	102 c
4	58 bc	102 c	88.9 c	10 b	104 b
6	57 ab	102 b	92.1 b	11 a	108 a
8	56 a	103 a	94.0 a	11 a	109 a
LSD *(P≤ 0.05)*	0.61	0.60	0.69	0.23	0.69
Cultivar					
Malakand-96	56 a	101 b	91.6 a	10	107 a
Parachinar	59 b	103 a	89.1 b	10	105 b
LSD *(P≤ 0.05)*	0.44	0.41	0.48	ns	0.49
CV (%)	7.4	2.7	3.6	7.5	2.5

There is a significant difference (P ≤ 0.05) among the means of the same group that are followed by different letters

Yield related attributes of soybean

Information on yield related attributes is provided in (Table 2). The outcomes indicate a favorable impact on yield-related traits of soybean cultivars with the incorporation of HA and FS. Nevertheless, the interaction between HA, FS and cultivars did not show statistical significance across all the examined traits. Mean data indicated that increasing HA doses increased pods plant^{-1}. When HA was employed at quantity of 9 kg ha^{-1}, more pods plant^{-1} (98) were documented in comparison to less pods plant^{-1} (90) observed in control. With respect to FS, the maximum pods plant^{-1} (99) was counted in plots treated with 8% followed by (96) pods plant^{-1} at t 6% of foliar Sulfur dose. Lowest values (89) were recorded in control. Among cultivars, Malakand-96 produced more pods (96) while least were associated with Parachinar (92). Maximum (3.7 cm) pod length was attained by applying HA level of 9 kg ha^{-1} followed by 6 kg ha^{-1} of (3.6 cm). Minimum pod length of (3.3 cm) was documented in control plot. Maximum pod length (3.6 cm) was recorded at 8% which were statistically similar (3.6 cm) when applied in 6%. Lowest pod length (3.3 cm) was observed in control. Among the cultivars Malakand-96 give lengthier pods (3.6 cm) and Parachinar gave shorter (3.4 cm). In response to HA at level of 9 kg ha^{-1} triggered more seeds pod^{-1} (2.60) followed by 6 kg ha^{-1} (2.4) while Less (2.3) seeds pod^{-1} were recorded in control plot. In case of FS, more (2.5) seed pod^{-1} were observed in plots sprayed with 8% which were at statistical parity with 6% (2.5) in comparison to less seed pod^{-1} (2.3) noted in control plot. Among the cultivars Malakand-96 resulted in maximum (2.5) seed pod $^{-1}$ while Parachinar had minimum (2.4) seed pod $^{-1}$. Heavier (174.7 g) seeds were collected from plots where HA was incorporated at the dose of 9 kg^{-1} followed by (171.0 g) at level of 6 kg ha^{-1}. Lowest (165.4 g) 1000 seed weight was collected from control plots. In regards to FS applied at the rate of 8% resulted in highest (173.1 g) in comparison to seed weight (167.1 g) recorded from control plots. Among the cultivars heavier (172.6 g) seeds were recorded in Malakand-96 while lowest (167.4 g) were found in Parachinar.

Table 2. Yield attributes of soybean cultivars as impacted by HA and FS application

Humic acid (kg ha^{-1})	Pods^{-1} plant	Pod length (cm)	Seed pod^{-1}	TSW (g)
0	90 c	3.31 d	2.32 c	165.4 c
3	93 b	3.41 c	2.40 bc	168.9 b
6	95 b	3.63 b	2.41 b	171.0 b
9	98 a	3.70 a	2.62 a	174.7 a
LSD *($P \leq 0.05$)*	1.26	0.03	0.03	1.23
Foliar Sulfur (%)				
0	89 d	3.31c	2.32 c	167.1 c
4	92 c	3.42 b	2.39 b	168.7 bc
6	96 b	3.61 a	2.50 a	171.2 ab
8	99 a	3.62 a	2.49 a	173.1 a
LSD *($P \leq 0.05$)*	1.26	0.03	0.03	1.23
Cultivar				
Malakand-96	96 a	3.61 a	2.49 a	172.6 a
Parachinar	92 b	3.39 b	2.38 b	167.4 b
LSD *($P \leq 0.05$)*	1.89	0.02	0.02	0.87
CV (%)	6.1	4.0	4.7	2.8

There is a significant difference ($P \leq 0.05$) among the means of the same group that are followed by different letters

Biological and grain yield

The (Table 3) presents data on biological and grain yield of soybean. The results showed significant influence on biological and grain yield of soybean cultivars due to the inclusion of HA and FS. Meanwhile, the interaction between HA and FS and cultivars did not exhibit statistical significance. Higher biological yield (12118 kg ha^{-1}) was delivered with application of HA at the dose of 9 kg ha^{-1} trailed by 6 kg ha^{-1} of (11498 kg ha^{-1}). Lower biological yield (10616 kg ha^{-1}) was noticed in untreated plots. In-case of FS, 8% FS sprayed had given maximum biological yield of (11820 kg ha^{-1}) compared to minimum (10588 kg ha^{-1}) biological yield recorded in untreated plots. Biological yield for Malakand-96 was higher (11533 kg ha^{-1}) as compared to yield (11236 kg ha^{-1}) produced by Parachinar cultivar. HA at dose of 9 kg ha^{-1} produced the highest grain yield (3106 kg ha^{-1}) compared to control, that recorded grain yield (2753 kg ha^{-1}) that was the lowest. FS applied at level of 8% also generated superior grain yield (3090 kg ha^{-1}). Though, lower (2798 kg/ha) grain yield was calculated from non-fertilized plot. Furthermore, soybean cultivar Malakand-96 showed greater grain yield (30042 kg ha^{-1}) as compared to Parachinar (2841 kg ha^{-1}).

Oil and protein content of soybean

Data related to oil and protein content of soybean cultivars when subjected to statistical analysis, revealed significant disparity as showed in (Table 3). The maximum oil content (21.0 %) was noted by the commencement of 9 kg ha^{-1} HA compared to control plots of (18.8 %). With the use of 8% FS higher amount of oil content (21.0%) was obtained while control plots had witnessed the lowest (18.8 %). Among the cultivars maximum (20.3 %) oil content was recorded in Malakand-96 while minimum (19.5 %) oil content was noted in Parachinar. Protein content was elevated with increasing dose of HA with the highest recorded in plots fertilized with 9 kg ha^{-1} (32.07 %) compared to lower protein content recorded in control plots (30.20 %). In terms of FS application more protein content (32.07 %) was produced when 8% FS was sprayed that was not different than results obtained with the application of FS sprayed at 6% (31.72 %) while the lowest protein was seen in unfertilized plots (29.95%). In last, Cultivar Malakand-97 recorded higher protein content (31.65 %) than Parachinar (30.71 %).

Table 3. Yield and quality of soybean cultivars as impacted by HA and FS application

Humic acid (kg ha^{-1})	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Oil content (%)	Protein content (%)
0	10616 c	2753 c	18.8 d	30.20 c
3	11307 b	2906 b	19.6 c	31.02 b
6	11498 b	3000 ab	20.2 b	31.44 b
9	12118 a	3106 a	21.0 a	32.07 a
LSD *($P\leq 0.05$)*	148	57	0.24	0.60
Foliar Sulfur (%)				
0	10588 d	2798 b	18.8 d	29.95 c
4	11095 c	2862 b	19.5 c	30.98 b
6	11740 b	3014 a	20.2 b	31.72 a
8	12116 a	3090 a	21.0 a	32.08 a
LSD *($P\leq 0.05$)*	148	57	0.24	0.60
Cultivar				
Malakand-96	11533 a	3042 a	25 a	31.65 a
Parachinar	11236 b	2841 b	24 b	30.71 b
LSD *($P\leq 0.05$)*	104	40	0.17	0.42
CV (%)	6.5	6.9	10.4	3.37

There is a significant difference ($P\leq 0.05$) among the means of the same group that are followed by different letters

Discussion

Results perceived for a variety of factors are addressed in this brief literature review for comparison. We observed significant effect of applied treated on soybean phenology, early establishment of flowers was seen with application of HA fertilizer compared to control. Humic acid may have favorably increased plant physiology lateral root initiation, dry matter production, hormonal activities cell respiration and nutrient absorption in cells of plant which may be the fundamental cause of it **[23]**. These outcomes are consistent with those found by [24, 25] who observed that HA-treated units experienced 50% early silking. FS also affected days to 50% flowering. Early establishment of flowers were observed by commencing FS compared to control because Sulfur encouraged the vegetative development, increasing levels of Sulfur reduced days taken to first flowering [26]. HA and FS significantly delayed 50% maturity contrasted to control plots. Humic acid is a supplement of nitrogen that releases nutrients gradually so the plants chlorophyll content grew and they stayed more vibrantly green for longer. Use of humic acid in crop growth may lead to a postponed maturity and an extended period for seed filling, as a result of the soil's increased fertility level (including macro and micro nutrients as well as organic matter) and higher available moisture [27]. Similar to this, FS also delayed maturity because of availability of nutrient for proper growth and development. reported late maturity with Sulfur fertilization.

Analysis of the data concerning growth attributes of soybean cultivars as influenced by HA and FS was significant. HA fertilization substantially increased leaves number compared to control plots because it influenced development metrics favorably because of endocrine and metabolic processes in plants. [28] reported that the use of humic acid resulted in a notable enhancement in the morphological traits, macronutrient content and chlorophyll content of legumes. Leaves count also increases with increasing levels of FS. Our results are similar to [29] who stated that growth tends to increase with the therapy of Sulfur. Same outcome was obtained by [30] who noted that when S was applied to sunflower plants the quantity of leaves tended to increase. A positive impact on plant height was prominent with higher doses of HA and FS. HA and FS at 9 kg ha^{-1} and 8 %, respectively showed higher plant height. Humic acid application improved soil conditions which encouraged nutrient absorption and availability to the plant and accelerated plant cell division, which may have contributed to the larger height of the plants. The identical results were noted by [31], according to them taller plant was obtained from humic acid applied plots. Plant development is accelerated by humic acid through the assimilation of both major and minor elements [32]. Similarly, the enhanced height is also because of Sulfur beneficial effects on cell development, enlargement and elongation which lead to a general increase in plant organs and more rapid and uniform vegetative growth of the produce [33]. Sulfur plays a significant part in vegetative development because it is a key component of the ferredoxin found in chloroplasts. Similarly, higher plants with Sulfur fertilization may be features of Sin plant metabolism and cell division, according to [34]. Maximum branches $plant^{-1}$ was produced from increasing amounts of humic acid. Because HA presence improved soil nutrient profile that may have accelerated cell development and division in growing plants leading to in rise in the amount of stems that have developed. These outcomes are consistent with [31, 34]. who discovered that as HA levels improve quantity of branches in soybean. The increase in branches $plant^{-1}$ was prominent with rising level of sulfur. The use of Sulfur increased the amount of branches because it directly affects the process of synthesizing chlorophyll and enzymatic activation. Sulfur plays a significant part in vegetative development because it is a key component of the ferredoxin found in chloroplasts. This is also in conformity with those results reported by [28] on Faba-bean, [35] who noticed improvement in mustard and [36] noticed that the submission of sulfur greatly enhanced primary branches in groundnut.

Positive influence of high doses of HA and FS was seen on yield related attributes of soybean cultivars. [37] documented that HA boost uptake of nutrients, improve the structure of the soil and increases yield and quality of various oilseed crops. Our findings are in connection with that of [38] who reported that humic acid-containing organic fertilizer significantly increased pods in spring soybean. [39] stated that pods plant^{-1} was significantly increased by humic acid. The increase in soybean pods is a result of Sulfur fertilization, which both directly and indirectly increases the amount of reproductive growth tissue. [36] observed that the treatment of Sulfur fertilizer greatly increased the quantity of groundnut pods produced for each plant.

The data analysis revealed a significant increase in the number of seed pods^{-1} in response to humic acid and foliar sulfur applications. Secondary beneficial effects of HA on chlorophyll levels, hormonal balance, and plant metabolic processes likely contribute to this increase. Study by [40] corroborates these findings, showing a positive impact of humic acid on seed quantity. Additionally, the application of sulfur significantly increased seed pod^{-1} production, likely due to its role in chlorophyll synthesis and pod growth, as supported by [41]. Further support these results by [42, 43], demonstrating the positive effects of sulfur fertilization on seed production in various crops. Humic acid application positively influenced the weight of 1000 seeds soybean cultivars is likely due to its enhancement of soil physiochemical properties and promotion of plant growth and development. This aligns with previous studies showing increased seed yield and dry matter partitioning with HA application in various crops [37, 44-46]. Similarly, foliar sulfur fertilization also led to an increase in the weight of 1000 seeds compared to control plots. The greater availability of sulfur likely improved the nutritional environment, enhancing carbohydrate metabolism and facilitating photosynthetic transfer to seeds, resulting in larger grains. These findings are supported by studies demonstrating heavier seeds with sulfur treatment [36, 47, 48].

Biomass yield of soybean cultivars improved considerably with increasing HA application. Our findings are in connection with those who demonstrated that HA can enhance crop growth and production. Its stated that dry matter of crop enhanced with application of HA. Similar to nitrogen fertilization, Sulfur fertilization had a favorable impact on the biological yield of soybean varieties. When the quantity of Sulfur fertilizer was raised, it resulted in effective photosynthesis, plants grew larger, increasing the biological output of the produce [47, 49]. The availability of Sulfur to plants fosters development due to the well-organized photosynthesis which ultimately increases crop biological output [50]. Similar to this, [51] found that a rise in Sulfur levels led to an increase in biological yield.

Grain yield exaggerated by higher doses HA and FS application. The superior seed yield was acquired from HA treated plants compared to control plots. [31] reported improvement in quantity of yield with enhancing levels of HA. According to [39] soil application of humic acid resulted in higher grain yield. Our outcomes are consistent with [52] they noticed that grain yield of snap bean enhanced by rising rates humic acid levels. Application of sulfur increased the grain yield of different varieties of soybean. In comparison to the control plot, a higher grain yield was achieved when sulfur was administered. It may be because soybeans have sinks in their foliage, where more photosynthetic materials are transported to the seed spot when the quantity of Sulfur is optimal [53]. [42] recorded more grain yield when Sulfur was applied together as foliar and soil. [54] also noted increased grain yield with application of Sulfur. Similarly, [55] found substantial rise in soybean grain yield with application of S fertilizer.

Analysis of the data regarding quality of soybean affected by humic acid and foliar Sulfur utilization was significant. Higher levels of HA resulted in higher oil concentration that might be a result of humic acid advantageous effects on plant and environmental characteristics. According to [37], HA amendments greatly increased oil content. Similar results were discovered by [31] who also looked into how humic acid-fertilized areas produced more oil. The percentage of soybean oil increased as a result of the addition of Sulfur fertilizer. Sulfur is regarded as the primary component needed to increase the output and caliber of oilseed products and main component of oil molecules, and its use raises the oil concentration of most oilseeds According to [53], The addition of sulfur increases groundnut protein and oil concentration [56]. According to [57] S fertilization results in an average 5% rise in oil concentration. Similar findings of higher S application boosting the protein and oil content in soybean seed were also made by [58]. Lakshman *et al*. [59] found that rising Sulfur levels increase the oil contents in soybean. This was a result that was similar to theirs. Improvement in seed protein was seen as result of higher HA and FS application compared to untreated units. Matuszak-Slamani *et al*. [60] found that application of humic acid fractions caused an increase in chlorophyll content, which is an indicator of plant protein content. Additionally, a transcriptomic analysis by [61] revealed that humic acid could relieve the inhibitory effect of high nitrogen on soybean nodulation, which indirectly suggests a potential impact on the protein content of soybean. Burkitbayev *et al*. [62] found that the use of powdered and solute sulfur-containing agrochemicals increased all protein fractions in soybeans. Moreover, a review of 76 peer-reviewed journal articles found that applying sulfur fertilizer increased protein and oil concentrations as well as yield [63].

Conclusion

Based on the results and conclusions drawn from our experimental study, it is evident that the application of humic acid HA at a rate of 9 kg ha^{-1} significantly enhanced both the growth and yield components of soybean cultivars. Moreover, foliar sulfur FS application at a rate of 8% demonstrated greater effectiveness compared to other doses. The cultivar Malakand-96 exhibited superior performance, yielding the maximum in terms of both overall yield and its components when compared to the Parachinar cultivar. In light of these findings, we recommend the combined application of humic acid HA at a rate of 9 kg ha^{-1} and 8% foliar sulfur FS for achieving higher yields specifically in the Malakand-96 cultivar of soybean, particularly in the agro-climatic conditions of Peshawar.

Author's contributions

Conceived and designed the experiments: MHA Khan & A Sohail, Performed the experiments: A Sohail, M Adil & A Iqbal: Contributed reagents/ materials/ analysis tools: I Ullah, Abdullah & U Bacha, Analyzed the data: S Rehman, M Adil & S Ahmad, Wrote the paper: U Ahmed.

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