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RESEARCH ARTICLE

Impact of humic acid and macronutrients on growth and yield of gobi sarson (*Brassica napus* L.) and succeeding pigeon pea (*Cajanus cajan* L.)

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Abstract

The present study was undertaken to assess the impact of humic acid and macronutrients on the growth and yield parameters of a gobi sarson-pigeon pea cropping system. The experiment involved the cultivation of gobi sarson (variety GSC 7) during the *Rabi* season of 2022-23 and pigeon pea (variety AL-882) during the *Kharif* season of 2023-24. The field experiment was conducted at the Agronomy Research Farm, Lovely Professional University and was laid out in a randomized block design (RBD) with three replications. A total of nine treatments comprising different combinations and concentrations of humic acid and macro-nutrients were evaluated to study their effects on the growth and yield attributes of both crops. Among various treatment T_9 [Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)] showed maximum plant height, number of primary and secondary branches, stem girth, dry matter accumulation and chlorophyll content in pigeon pea showed higher values than gobi sarson, likely due to residual soil nutrient enhancement. Yield attributes improved with an increase in humic acid and macronutrients and treatment T_9 [Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)] had maximum number of pods per plant, pod length (cm), number of seeds per pod, test weight (g) and seed yield (q/ha) in pigeon pea crop in comparison to gobi sarson crop. Results from the study revealed that among the various treatments, the application of T_9 [Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)] had a significant impact on various growth and yield attributes. Pigeon pea crop had more yield as a succeeding crop as soil absorbs more nutrients from the previous grown crop (gobi sarson) and enhances the growth and yield characters. Humic acid macroelements significantly increases test weight and seed yield, demonstrating its positive impact on the overall crop production of gobi sarson-pigeon pea crop.

Keywords: growth parameters; humic acid; macronutrients; oilseed crop; pigeon pea; quality; yield attributes

Introduction

Gobi sarson, formally classified as *Brassica* sp., is a significant oil crop of worldwide importance. It is a member of the *Brassicaceae* family, formerly known as *Cruciferae*. Indigenously, it is commonly known as Sarson, Toria, or Yellow Toria. Gobi sarson thrives at cold temperatures, making them suitable for growth and production in both tropical and temperate regions (1). Due to its shorter lifetime and greater adaptation to various soil types and multiple agro-climatic areas, it has emerged as a potential and significant oilseed crop. Gobi sarson account for approximately 33 % of India's oil production, making it the primary edible oilseed crop in the country. India is the leading country in terms of gobi sarson-mustard cultivation, covering an area of 6.32 million hectares (2, 3). In terms of output, India is second only to China, contributing 7.39 million metric tons to the world total. It is a brief-term crop mostly cultivated as a winter season crop in Assam, Bihar, West Bengal, Odisha and certain parts of eastern Uttar Pradesh. Gobi Sarson is the dominant oilseed crop in Assam, covering over 90 % of the state's territory and production (4). India has a significant impact on the global oil sector as it contributes around 12 % of the total global oil output. Furthermore, it accounts for around 33 % of global oil consumption (5).

Pigeon pea, scientifically known as *Cajanus cajan*, is a significant legume crop in Asia. It holds a distinct position in Indian agriculture, with India being responsible for around 90 % of its worldwide output. It has several functions as food, feed, fodder and fuel (6). It is a highly beneficial protein source, containing 20-22 % protein. It may be used to enhance the energy content of vegetarian diets that mostly consist of cereals. It reported that a notable accomplishment in grain legume production in India is the successful cultivation of pigeon pea as a *Rabi* (winter) crop (7, 8). Pulses, along with other grains, are crucial sources of protein in the global diet (9). The use of humic acid and macronutrients is crucial for attaining self-sufficiency in oil production (10).

Humic acid is a naturally occurring complex compound that forms when organic matter in soil, peat and lignin decomposes. It may be utilized to enhance crop yield. Humic acid is a significant chemical input for sustainable crop production. Humic acid has a significant impact on plant root development (11). Humic acids given to the soil improved root initiation and boosted root development. Humic compounds' stimulatory effects have been linked to increased uptake of macronutrients. It is also considered a plant hormone-like chemical that minimizes soil erosion and enhances soil water holding capacity, hence improving crop drought tolerance (12). Applying humic acid directly to the leaves (foliar application) can also enhance plant development and the accumulation of photosynthetic substances. It is important to differentiate between the indirect and direct impacts of humic acid on plant development (11, 12). Humic acid has several direct and indirect impacts on plant growth, such as enhancing photosynthesis, protein synthesis, nutrient availability, chelating metal cations, improving soil structure, boosting water holding capacity and enhancing the cation exchange capacity of soil (13). Humic compounds enhance the microbial community in soil and aid in mitigating metal toxicity. Enhancing soil conditions and achieving balance in plant nutrients are crucial for maximizing soil productivity and plant yield. They have auxin-like properties, enhancing cellular division and elongation (14).

Oilseed crops have increased resilience to environmental stressors such as drought and heat due to the presence of greater levels of magnesium. This results in reliable crop production and enhances the sustainability of farming activities in the long run. Sulphur is a vital element for the growth and maturation of oilseed crops since it has a significant impact on the structure of cell walls (15). Crops cannot achieve their maximal production potential on soils deficient in humic acid and macronutrients, regardless of the addition of other nutrients or the implementation of improved crop management strategies. Strategic use of humic acid and macro elements can enhance the stability and long-term viability of the gobi sarson-pigeon pea system. Thus, the present study was utilized to evaluate the effect of humic acid and macronutrients on the growth and yield attributes of gobi sarson and pigeon pea.

Materials and methods

Experimental site

The present investigation was conducted during the *Kharif* and *Rabi* seasons of 2022-2024 to evaluate the performance of two important crops gobi sarson (*Brassica napus)* and pigeon pea (*Cajanus cajan*). Gobi sarson was sown on 17th November 2022 during the *Rabi* season, while pigeon pea was sown on 20th June 2023 during the *Kharif* season. The experimental design adopted for both crops was the randomized block design (RBD) with appropriate replications. The present work was conducted at the field of School of Agriculture, Lovely Professional University, Phagwara, Punjab during 2022-24. Geographically, Lovely Professional University is located at a distance of 8 km from the Phagwara. It falls in a sub-tropical climate situated at 31° 13′28″ North latitude and 75° 46′25″ East longitude with an altitude of 245 m above the mean sea level (AMSL).

Experimental materials

Both crop varieties procured from Punjab Agriculture University (PAU) Ludhiana used in the experiment where, gobi sarson was GSC 7, with a seed rate of 4 kg/ha. Each plot measured 15 m^2 (5 m × 3 m) with a spacing of 30 cm between rows and 10 cm between plants. For pigeon pea, the variety AL-882 was selected and seeds were sown at a rate of 15 kg/ha. Similar to gobi sarson, the plot size was maintained at 15 m^2 (5 m × 3 m), with a spacing of 45 cm × 15 cm between rows and plants, respectively. All recommended agronomic practices were followed uniformly across the experimental plots to ensure proper crop establishment and growth.

Experimental design

The randomised block design (RBD) which composed of 9 treatments in 3 replications. The different treatments include T_1 - Control, T_2 - Humic acid (10 g/L), T_3 - Sulphur (5 g/L), T_4 - Magnesium (5 g/L), T_5 - Sulphur (5 g/L) + Magnesium (5 g/L), T_6 - Humic acid (10 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L), T_7 - Humic acid (15 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L), T_8 - Humic acid (5 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L), T_9 - Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L).

Experimental data

The doses of humic acid and macro-nutrients were uniformly applied across all experimental plots to ensure consistency in treatment effects. In the case of gobi sarson, foliar applications were carried out at 45, 75 and 105 days after sowing (DAS), following the crop's growth stages. Similarly, for pigeon pea, foliar sprays of the respective treatments were also administered at 45, 75 and 105 DAS. These time intervals were selected to coincide with key physiological stages to maximize the uptake and effectiveness of the applied nutrients and humic acid.

The data for growth and yield attributes of gobi sarson-pigeon pea were recorded using three random chosen plants from each treatment after seed sowing. For growth characters plant height (cm), number of primary and secondary branches, stem girth, dry matter accumulation and chlorophyll content studied.

The yield attributes recorded for the gobi sarson-pigeon pea crop are the number of siliquae per plant, length of siliqua (cm), number of seeds per silique, test weight (g), seed yield (q/ha).

Statistical analysis

The data collected from the present piece of work at different growth stages were subjected to statistical analysis. The statistical analysis was carried out by using the software OPSTAT and found that most of the parameters considered for this experiment were significant at $p < 0.05$ and shows a significant difference among the treatments at all the time of observations.

Results and Discussion

Influence of treatments on growth parameters of gobi sarson -pigeon pea crop

Growth parameters including plant height (cm), number of primary and secondary branches (Table 1, Fig. 1), stem girth, dry matter accumulation and chlorophyll content (Table 2, Fig. 1) were significantly influenced by the humic acid and macronutrients application.

Plant height

Growth characters such as plant height increased significantly with increasing the levels of humic acid and macroelements (Table 1, Fig. 1). Significant differences were observed in plant height of both gobi sarson and pigeon pea across treatments. In gobi sarson, the tallest plants were recorded under T_9 (181.33 cm), followed by T_7 (180.33 cm) and T_6 (180.00 cm), while the shortest plants were observed in the control (T_1, 166.57 cm). Similarly, in pigeon pea, T_9 also resulted in the highest plant height (215.17 cm), closely followed by T_7 (213.03 cm) and T_6 (212.27 cm), whereas the lowest height was found in T_1 (194.73 cm). The consistent increase in plant height with combined application of humic acid (especially at 20 g/L), sulphur and magnesium suggest a synergistic effect in enhancing vegetative growth in both crops (Fig. 2). This may be attributed to the stimulation of stem elongation, which promotes cell division and elongation in stem tissues. This can lead to taller plants with more robust stems by the application of humic acid and enzyme activation in metabolic processes sulphur supports the production of proteins and enzymes necessary for cell growth and division, which can indirectly influence plant height. The application of humic acid and macronutrients caused the best growth performance and have a direct role in absorption by plants either through cuticle or stomata and have a significant role in photosynthesis activity in plant leaves which improves the plant height. This increase in plant height may be attributed to the stimulation of cell division, intermodal extension and elongation induced by the combined application of humic acid and macronutrients, resulting in longer stems. These findings align with previous research (19) in gobi sarson crop. The increased plant height with T_9, T_7 and T_6 suggests the positive impact of the combined application of humic acid and macronutrients. Humic acid and macronutrients influence cell growth and division processes, contributing to enhanced stem elongation and ultimately, taller plants. Additionally, incorporating humic acid and macronutrients further supported these growth-promoting effects reported in the previous study in capsicum (20).

Number of primary branches

Data related to number of primary and secondary branches of gobi sarson crop varied significantly at all stages of growth (Table 1, Fig. 1). The number of primary branches per plant also varied significantly among treatments in both crops. In gobi sarson, the maximum number of primary branches was recorded in T_9 (8.53), T_7 (8.20) and T_6 (8.03), while the minimum was observed in the control T_1 (4.40). A similar trend was noted in pigeon pea, where T_9 (14.60) recorded the highest number of primary branches, followed by T_7 (14.43) and T_6 (14.13), with the lowest in T_1 (10.30). These results indicate that the combined application of humic acid along with sulphur and magnesium significantly promotes branching in both crops compared to control and single nutrient treatments (Fig. 2). This might be because the primary branches of mustard plants benefit from humic acid by developing stronger and more vigorous growth. Improved root health and nutrient uptake lead to better support for the main stem and

Table 1. Plant height (cm), number of primary, secondary branches of gobi sarson and pigeon pea crop as influenced by different levels of humic acid and macronutrients

Treatments	Plant height (cm)		No. of primary branches		No. of secondary branches	
	Gobi sarson	Pigeon pea	Gobi sarson	Pigeonpea	Gobi sarson	Pigeonpea
T_1 - Control	166.57^{d}	194.73^{f}	4.40^{c}	10.30^{d}	5.33^{d}	15.30^{c}
T_2 - Humic acid (10 g/L)	173.27^{cd}	202.53^{de}	6.23^{b}	11.43^{d}	7.10^{cd}	16.43^{bc}
T_3 - Sulphur (5 g/L)	173.07^{cd}	201.37^{e}	6.13^{b}	11.17^{d}	7.02^{cd}	16.57^{bc}
T_4 - Magnesium (5 g/L)	173.03^{cd}	199.17^{ef}	6.07^{b}	10.77^{d}	6.97^{cd}	16.70^{abc}
T_5 - Sulphur (5 g/L) + Magnesium (5 g/L)	173.67^{bcd}	206.53^{cd}	7.07^{ab}	12.43^{c}	7.37^{c}	19.03^{ab}
T_6 - Humic acid (10 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	180.00^{abc}	212.27^{ab}	8.03^{a}	14.13^{ab}	8.67^{abc}	18.17^{ab}
T_7 - Humic acid (15 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	180.33^{ab}	213.03^{ab}	8.20^{a}	14.43^{a}	9.50^{ab}	19.43^{a}
T_8 - Humic acid (5 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	174.00^{bc}	210.53^{bc}	7.20^{ab}	13.23^{bc}	8.17^{bc}	18.43^{ab}
T_9 - Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	181.33^{a}	215.17^{a}	8.53^{a}	14.6^{a}	10.33^{a}	19.13^{ab}
S. Em ±	**2.11**	**1.35**	**0.47**	**0.33**	**0.54**	**0.83**
CD	**6.34**	**4.05**	**1.43**	**0.99**	**1.62**	**2.50**

Table 2. Stem girth (cm), dry matter accumulation (g), chlorophyll index of gobi sarson and pigeon pea crop as influenced by different levels of humic acid and macronutrients

Treatments	Stem girth (cm)		Dry matter accumulation (g)		Chlorophyll index	
	Gobi sarson	Pigeon pea	Gobi sarson	Pigeon pea	Gobi sarson	Pigeon pea
T_1 - Control	5.37^{c}	5.48^{f}	58.67^{c}	205.63^{f}	20.57^{c}	41.90^{d}
T_2 - Humic acid (10 g/L)	6.89^{bc}	6.90^{e}	71.73b	209.70^{e}	26.67^{b}	44.37^{c}
T_3 - Sulphur (5 g/L)	6.64^{c}	6.72^{e}	71.23^{b}	209.20^{e}	26.20^{bc}	44.03^{c}
T_4 - Magnesium (5 g/L)	6.88^{bc}	7.08^{e}	71.05^{b}	208.77^{e}	25.93^{bc}	43.87^{cd}
T_5 - Sulphur (5 g/L) + Magnesium (5 g/L)	7.70^{abc}	7.76^{d}	73.20^{b}	211.73^{d}	27.53^{b}	45.6^{bc}
T_6 - Humic acid (10 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	13.62^{a}	13.78^{b}	84.97^{a}	215.03^{b}	38.27^{a}	47.93^{a}
T_7 - Humic acid (15 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	13.35^{ab}	13.47^{b}	85.37^{a}	216.77^{a}	38.43^{a}	48.20^{a}
T_8 - Humic acid (5 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	8.22^{abc}	8.37^{c}	74.33^{ab}	213.13^{c}	28.67^{b}	47.33^{ab}
T_9 - Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	14.11^{a}	14.82^{a}	85.77^{a}	217.67^{a}	38.70^{a}	48.77^{a}
S. Em ±	**1.96**	**0.01**	**3.58**	**0.37**	**1.57**	**0.54**
CD	**5.89**	**0.05**	**10.75**	**1.11**	**4.71**	**1.62**

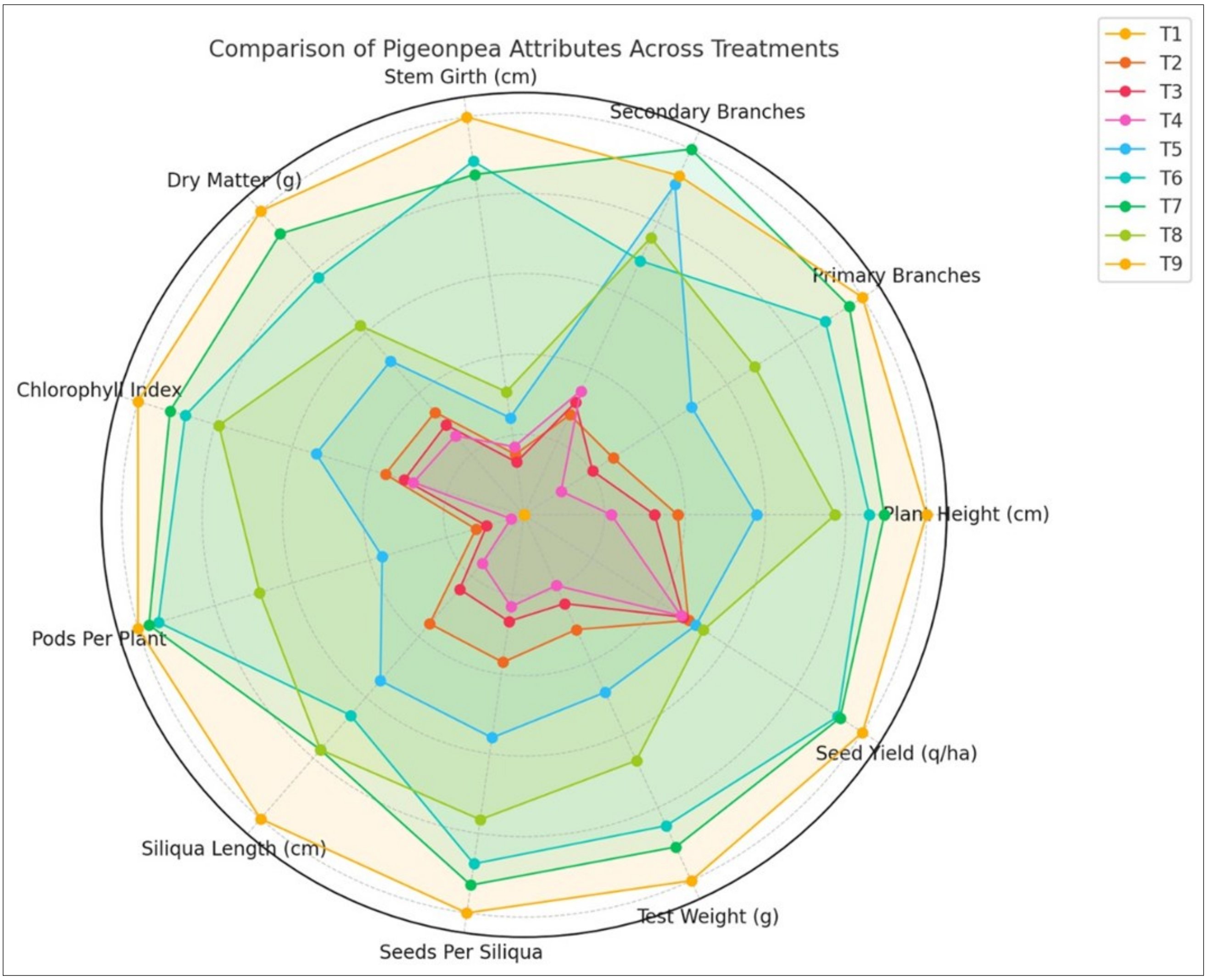

Fig. 1. Radar graph depicting the influence of different treatments on growth and yield attributes of pigeon pea.

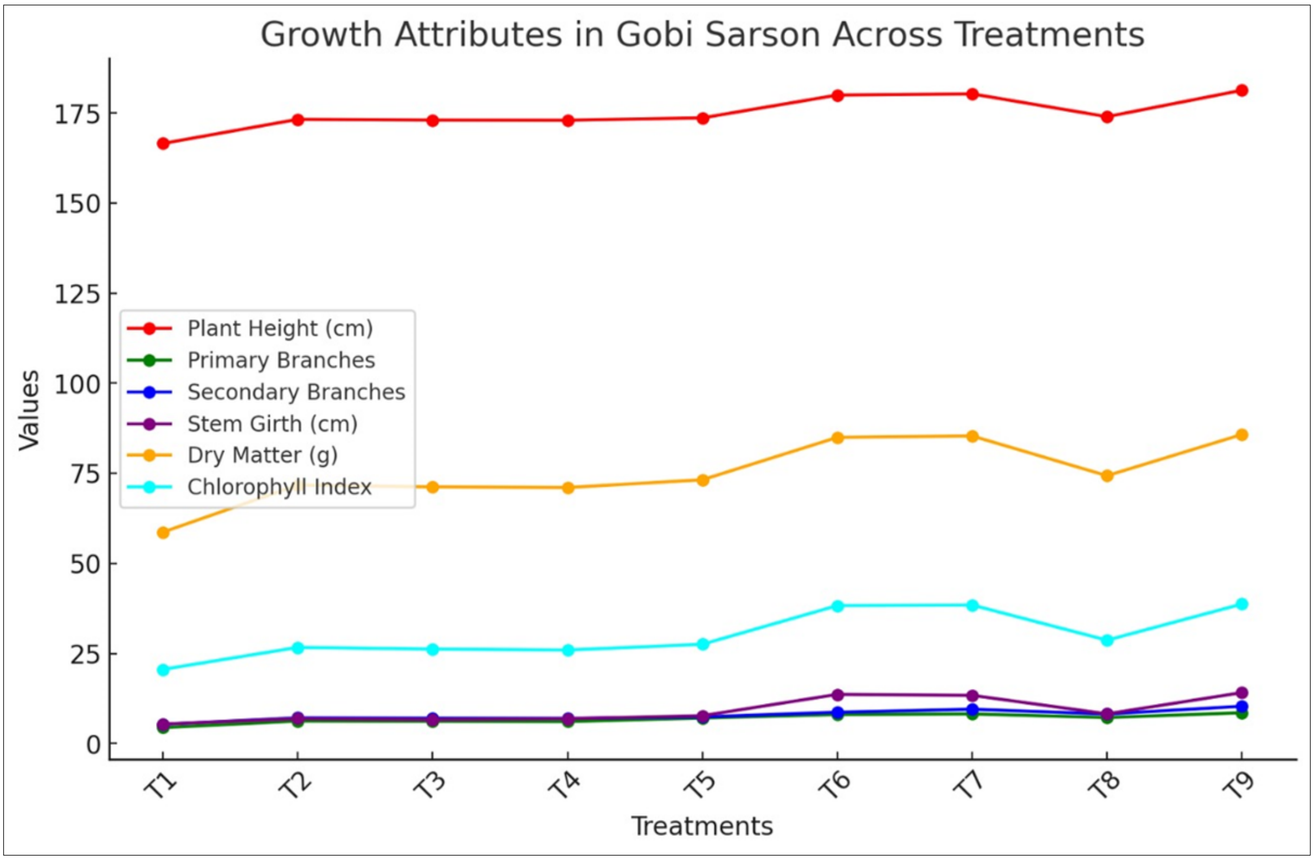

Fig. 2. Line chart representing the growth attributes of gobi sarson across different treatments.

primary branches. Secondary branches often benefit even more from the improved overall plant health and nutrient availability. The genetic makeup of the cultivar with enough humic acid and macronutrients may have improved the physical and chemical properties of the soil, allowing the plants to uptake the nutrients and potentially promoting maximum plant volume and number of primary branches of crop. Similar results were reported in the earlier studies in gobi sarson (21) and pigeon pea (22) crop.

Number of secondary branches

Data related to number of secondary branches of crops varied significantly at all stages of growth (Table 1, Fig. 1). For the number of secondary branches, T9 again outperformed all other treatments in gobi sarson with 10.33 branches, followed by T_7 (9.50) and T_6 (8.67), whereas the lowest was recorded in T_1 (5.33). In pigeon pea, the highest secondary branching was observed in T_7 (19.43), T_9 (19.13) and T_5 (19.03), while the control T_1 recorded the lowest (15.30). The increase in secondary branching in response to combined nutrient treatments highlights the role of humic acid and macro-nutrients in enhancing the plant's structural development in both cropping systems. Secondary branches often benefit even more from the improved overall plant health and nutrient availability. Similar results were reported in gobi sarson (21) and pigeon pea (22) crop.

Stem girth

Stem girth of gobi sarson was differed significantly among different treatments (Table 2, Fig. 1). Stem girth was significantly influenced by different treatments in both gobi sarson and pigeon pea. In gobi sarson, the highest stem girth was recorded under T_9 (14.11 cm), followed closely by T_6 (13.62 cm) and T7 (13.35 cm), indicating a strong positive effect of higher doses of humic acid (20 g/L) combined with sulphur and magnesium. The lowest stem girth was observed in T_1 (5.37 cm). A similar pattern was noted in pigeon pea, where the maximum stem girth was observed under T_9 (14.82 cm), followed by T_6 (13.78 cm) and T_7 (13.47 cm), while the minimum was found in the control treatment T_1 (5.48 cm) (Fig. 2). Treatments with combined applications consistently outperformed single nutrient applications, reflecting the enhanced stem thickening due to synergistic nutrient effects. Humic acids can enhance the production of growth hormones like auxins, which are involved in cell elongation and division. Magnesium is a central component of chlorophyll, the pigment responsible for photosynthesis. Adequate magnesium ensures efficient photosynthesis, leading to better energy production and growth, which can contribute to increased stem girth. Magnesium activates various enzymes involved in crucial metabolic processes, including those related to protein synthesis and nucleic acid production. It helps in the uptake and transport of other essential nutrients within the plant. Adequate magnesium levels can ensure that the plant efficiently acquires and uses nutrients needed for stem development. Results indicated that stem girth was more in pigeon pea crop as compared to gobi sarson crop. There is a correlation between the growth in stem girth and the accessibility of the presence of nutrients in the root zone. This results in an increase in the girth of the stem as well as other growth characteristics. Similar findings are reported in the former studies in gobi sarson (23) and pigeon pea (24) crop.

Dry matter accumulation

Dry matter accumulation of gobi sarson were differed significantly at harvest in (Table 2, Fig. 1). Dry matter accumulation showed significant variation across treatments in both crops. In gobi sarson, the highest dry matter accumulation was observed under T_9 (85.77 g), T_7 (85.37 g) and T_6(84.97 g), whereas the lowest value was found in the control treatment T_1(58.67 g). In pigeon pea as well, T_9 (217.67 g) recorded the highest dry matter accumulation, followed by T_7 (216.77 g) and T_6 (215.03 g), with the least accumulation noted in T_1 (205.63 g). These results clearly indicate that the combined application of humic acid with sulphur and magnesium, especially at higher humic acid concentrations, substantially enhances biomass production in both gobi sarson and pigeon pea (Fig. 2). The application of humic acid, calcium (Ca) and magnesium (Mg) can significantly influence the dry matter accumulation of plants. Each of these components plays a unique role in plant growth and development, contributing to increased biomass and overall plant health. Humic acid improves soil structure and increases the availability of nutrients, including calcium and magnesium. This leads to better nutrient uptake and more efficient use of resources, promoting increased dry matter accumulation. By enhancing soil aggregation, humic acid improves root growth and development. Better root systems can access more nutrients and water, which supports higher biomass production. The increase in the dry matter accumulation can be attributed to the vital role of humic acid and macronutrients in facilitating energy transfer and translocation within plants. Magnesium and Sulphur nutrients are essential for the processes of photosynthesis, osmotic regulation, cell formation, stomatal regulation and the development of the plant's water structure. Application of humic acid and macronutrients which causes an increase in vegetative development by activating several plant enzymes. This might be the cause of the increased dry matter. Similar trend was followed in the previous studies in gobi sarson (25) and pigeon pea (26) crop.

Chlorophyll index

Chlorophyll content, measured in SPAD units, data obtained are presented in (Table 2, Fig. 1). Chlorophyll content, measured as the chlorophyll index, significantly increased under combined nutrient applications in both crops. In gobi sarson, the maximum chlorophyll index was recorded under T_9 (38.70), followed closely by T_7 (38.43) and T_6 (38.27), showing significant improvement over the control T_1 (20.57). Similarly, pigeon pea exhibited the highest chlorophyll index under T_9 (48.77), followed by T_7 (48.20) and T_6 (47.93), while the lowest was in the control T_1 (41.90) (Fig. 2). Treatments with single nutrient applications showed moderate improvements, but the most notable increases in chlorophyll content were observed under combined treatments, indicating improved photosynthetic efficiency and overall plant health. The foliar application of humic acid and macroelements can significantly impact the chlorophyll index of plants, which is a key indicator of plant photosynthetic efficiency. Humic acid can enhance the uptake and efficiency of macroelements, leading to better results in chlorophyll production. The combined application can optimize nutrient availability and reduce stress, resulting in higher chlorophyll levels. The results indicated that pigeon pea crop had more chlorophyll index as compared to gobi sarson as compared to pigeon pea crop. Applications of humic with macronutrients revealed significant increments in chlorophyll index over the control treatment. The application of humic acid and macronutrients caused the best growth performance and have a direct role in absorption by plants either through cuticle or stomata and have a significant role in photosynthesis activity in plant leaves which improves the chlorophyll index. The noticeable increase in chlorophyll content can be attributed to the combined application of humic acid and macronutrients, which seem to protect chlorophyll by reducing its degradation. This preservation of chlorophyll content can significantly impact the plant's photosynthetic activity, contributing to enhanced plant growth and development. The results are consistent with previous findings in the previous studies gobi sarson (27) and pigeon pea (28) crop.

Influence of treatments on yield parameters of gobi sarson-pigeon pea crop

Yield attributes including number of siliquae per plant, siliqua length (cm), number of seeds per silique, test weight (g) and seed yield (q/ha) were significantly influenced by foliar application of humic acid and macronutrients are presented in Table 3 and 4 for gobi sarson and pigeon pea crop.

Number of siliqua/pods per plant

The number of siliquae in gobi sarson and pods in pigeon pea significantly increased with the application of humic acid and macro-nutrients. In gobi sarson, the maximum number of siliquae per plant was recorded under T_9 (338.33), followed closely by T_7 (337.00) and T_6 (336.67), while the lowest count was observed in the control T_1 (292.33). Similarly, in pigeon pea, the highest number of pods per plant was observed under T_9 (133.47), followed by T_7 (133.00) and T_6 (132.60), whereas the minimum was recorded in T_1 (116.97) (Table 3, Fig. 3). These results clearly suggest that the combined application of humic acid (particularly at higher doses) with sulphur and magnesium significantly enhances reproductive development in both crops.

Siliqua/pod length (cm)

Siliqua/pod length was also significantly affected by different

Table 3. Yield attributes viz., number of siliquae/pods per plant, siliqua/pod length (cm), number of seeds per siliqua/pod of gobi sarson and pigeon pea crop as influenced by different levels of humic acid and macronutrients

Treatments	Number of siliquae/pods per plant		Siliqua/Pod length (cm)		Number of seeds per siliqua/pod	
	Gobi sarson	Pigeonpea	Gobi sarson	Pigeonpea	Gobi sarson	Pigeonpea
T_1 - Control	292.33^{c}	116.97^{d}	7.00^{c}	5.97^{e}	20.47^{f}	3.07^{e}
T_2 - Humic acid (10 g/L)	310.67^{bc}	119.03^{d}	7.73^{bc}	6.60^{cd}	23.67^{de}	3.97^{d}
T_3 - Sulphur (5 g/L)	310.00b^{c}	118.57^{d}	7.63^{bc}	6.40^{de}	23.20^{de}	3.72^{d}
T_4 - Magnesium (5 g/L)	309.33^{bc}	117.53^{d}	7.47^{c}	6.25^{de}	22.97^{e}	3.63^{d}
T_5 - Sulphur (5 g/L) + Magnesium (5 g/L)	313.33^{b}	123.03^{c}	7.90^{abc}	6.93^{bc}	24.50^{de}	4.43^{c}
T_6 - Humic acid (10 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	336.67^{a}	132.60^{a}	9.40^{ab}	7.13^{b}	27.53^{bc}	5.20^{ab}
T_7 - Humic acid (15 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	337.00^{a}	133.00^{a}	9.63^{a}	7.33^{ab}	28.83^{ab}	5.33^{a}
T_8 - Humic acid (5 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	316.33^{b}	128.27^{b}	7.99^{abc}	7.33^{ab}	25.40^{cd}	4.93^{b}
T_9 - Humic acid (20 g/L) + Sulphur (5 g/L) + Magnesium (5 g/L)	338.33^{a}	133.47^{a}	9.47^{ab}	7.73^{a}	29.90^{a}	5.50^{a}
S. Em ±	**5.55**	**1.23**	**0.55**	**0.13**	**0.73**	**0.12**
CD	**16.63**	**3.68**	**1.66**	**0.39**	**2.19**	**0.36**

Table 4. Yield attributes viz., test weight (g), seed yield (q/ha) of gobi sarson crop as influenced by different levels of humic acid and macronutrients

Treatments	Test Weight (g)		Seed Yield (q/ha)	
	Gobi sarson	Pigeon pea	Gobi sarson	Pigeon pea
T_1 - Control	2.23^{e}	3.17^{e}	19.77^{c}	19.77^{b}
T_2 - Humic acid (10g/L)	2.97^{cd}	4.63^{d}	21.97^{bc}	21.97^{ab}
T_3 - Sulphur (5g/L)	2.87^{d}	4.30^{d}	21.90^{bc}	21.90^{ab}
T_4 - Magnesium (5g/L)	2.77^{de}	4.07^{d}	21.87^{bc}	21.87^{ab}
T_5 - Sulphur (5g/L) + Magnesium (5g/L)	3.13^{bcd}	5.43^{c}	22.07^{ab}	22.07^{ab}
T_6 - Humic acid (10g/L) + Sulphur (5g/L) + Magnesium (5g/L)	3.43^{abc}	7.13^{a}	23.97^{ab}	23.97^{a}
T_7 - Humic acid (15g/L) + Sulphur (5g/L) + Magnesium (5g/L)	3.60^{a}	7.40^{a}	24.00^{ab}	24.00^{a}
T_8 - Humic acid (5g/L) + Sulphur (5g/L) + Magnesium (5g/L)	3.23^{abcd}	6.30^{b}	22.17^{ab}	22.17^{ab}
T_9 - Humic acid (20g/L) + Sulphur (5g/L) + Magnesium (5g/L)	3.70^{a}	7.83^{a}	24.17^{a}	24.30^{a}
S. Em ±	**0.16**	**0.23**	**0.65**	**0.02**
CD	**0.49**	**0.70**	**1.96**	**0.06**

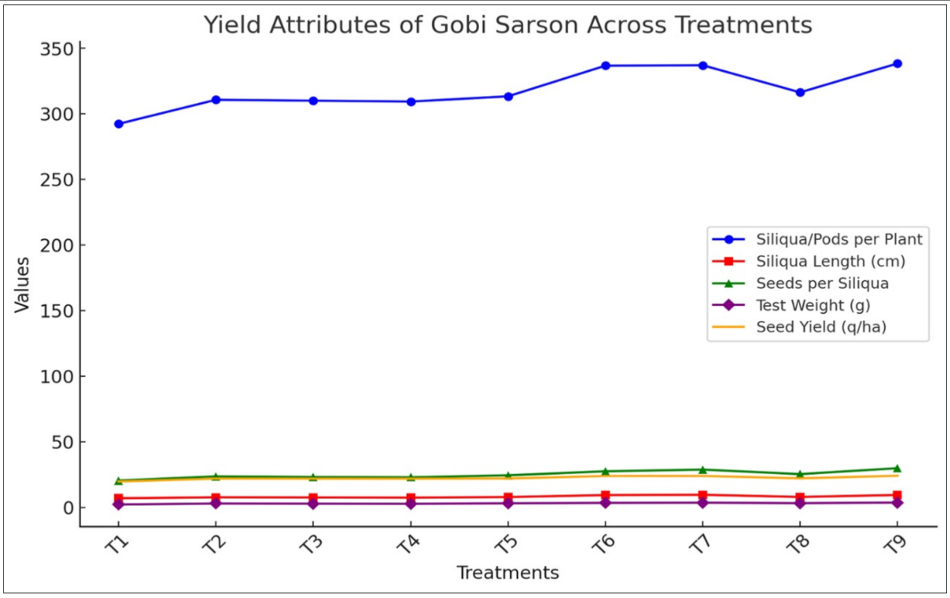

Fig. 3. Line chart representing the yield attributes of gobi sarson across different treatments.

treatments. In gobi sarson, the longest siliquae were observed in T_7 (9.63 cm), followed by T_9 (9.47 cm) and T_6 (9.40 cm), while the shortest was recorded in T_1 (7.00 cm). A similar pattern was observed in pigeon pea, where the maximum pod length was noted under T_9 (7.73 cm), followed by T_7 (7.33 cm) and T_8 (7.33 cm), with the shortest length in T_1 (5.97 cm) (Table 3, Fig. 3). This demonstrates the positive influence of combined nutrient applications on pod elongation, which is critical for seed development.

Number of seeds per siliqua/pod

The number of seeds per siliqua in gobi sarson and per pod in pigeon pea exhibited significant improvement with nutrient treatments. In gobi sarson, T_9 (29.90) produced the highest number of seeds per siliqua, followed by T_7 (28.83) and T_6 (27.53), whereas the lowest was observed in the control T_1 (20.47). In pigeon pea, the highest seed count per pod was again recorded in T_9 (5.50), with T_7 (5.33) and T_6 (5.20) also performing well, while the lowest was in T_1 (3.07) (Table 3, Fig. 3). These findings highlight that the synergistic application of humic acid, sulphur and magnesium, especially at higher humic acid concentrations, significantly boosts seed-setting potential in both crops.

Test weight (g)

Test weight, an important indicator of seed quality, showed significant variation across treatments in both gobi sarson and pigeon pea. In gobi sarson, the highest test weight was recorded under T_9 (3.70 g), followed by T_7 (3.60 g) and T_6 (3.43 g), while the lowest value was observed in the control T_1 (2.23 g). A similar trend was evident in pigeon pea, where the maximum test weight was again under T9 (7.83 g), followed by T_7 (7.40 g) and T_6 (7.13 g), whereas the minimum was recorded in T_1 (3.17 g) (Table 4, Fig. 3). These results indicate that higher doses of humic acid in combination with sulphur and magnesium significantly improved seed weight in both crops, likely due to enhanced nutrient availability and better seed filling.

Seed yield (q/ha)

Seed yield was significantly influenced by nutrient treatments in both gobi sarson and pigeon pea. The highest seed yield in gobi sarson was obtained from T_9 (24.17 q/ha), followed closely by T_7 (24.00 q/ha) and T_6(23.97 q/ha), while the lowest yield was recorded in the control T_1 (19.77 q/ha). Similarly, pigeon pea showed maximum yield under T_9 (24.30 q/ha), followed by T_7 (24.00 q/ha) and T_6 (23.97 q/ha), with the least yield in T_1 (19.77 q/ha) (Table 4, Fig. 3). Treatments with combined applications, especially at higher concentrations of humic acid, consistently outperformed single applications, indicating a strong synergistic effect in improving crop productivity.

The combined effect of humic acid and macronutrients causes number of siliquae per plant, siliquae length and number of seeds per silique which was the outcome of improved photosynthate translocation from source to sink is likely responsible for the increase in seed yield under adequate nutrient supply. Similar results were reported in previous studies in gobi sarson crop (16). This may be because humic acid and macronutrients promoted more efficient allocation of photosynthates to reproductive areas, resulting in higher test weight and seed yield. The increased accessibility of essential nutrients in plants, achieved by the transportation of photosynthates that have accumulated in response to nutrient availability, may be responsible for the greater yield characteristics. The application of higher doses of humic acid and macronutrients resulted in an elevation of these yield-enhancing traits. This was due to the availability of ample nutrients during the whole growth period of the crop, which led to enhanced vegetative growth and development of gobi sarson plants. Similar, results are indicated in the previous studies in gobi sarson crop (17, 18).

The rise in seed production due to adequate nutrient delivery can primarily be attributable to the synergistic effect of a greater quantity of number of pods/plant, an increased pod length and number of seeds/pod. Similar, findings were obtained in gobi sarson crop (27). This might be attributed to the fact that the presence of humic acid and macroelements resulted in an enhanced distribution of photosynthate to the reproductive parts of the plant, leading to increased production of both test weight and seed yield. Transporting the stored nutrients produced by photosynthesis due to nutritional influence can enhance the accessibility of almost all essential plant nutrients, leading to higher crop yields. The value of these yield-enhancing properties was boosted by higher dosages of humic acid and macroelements, as they provided sufficient nutrients for the whole crop growth period, hence promoting the vegetative growth and development of pigeon pea crop. Similar results are concluded in the previous study in pigeon pea crop (27, 29).

Conclusion

Different levels of humic acid and macronutrients treatments are tested in terms of their impact on gobi sarson-pigeon pea growth and yield attributes. It was concluded from the results that the application of T_9 treatment improves the growth and yield components of gobi sarson-pigeon pea crop. The use of humic acid and macroelements significantly influences the growth and yield characteristics. Overall, pigeon pea crop had more yield as compared to gobi sarson crop. This increasing effect may also be related to the nutrient's beneficial effect on metabolism and biological activity, as well as its stimulating effect on photosynthetic pigments and enzymatic activity. These elements help to promote plant vegetative growth and production. As a result, it is recommended to use humic acid and macronutrients to increase the yield components of the pigeon pea crop. Foliar application of humic acid and macroelements generally leads to an increase in the chlorophyll index by improving nutrient availability and plant health. This method can be particularly effective for rapidly addressing nutrient deficiencies and enhancing plant performance. This study was limited to single location and season, further multi location trials are recommended.

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Authors' contributions

AB carried out the experiment, took observations and analyzed the data. CK guided the research by formulating the research concept and approved the final manuscript. SY, SV, RK and SK participated in the design of the study and performed the statistical analysis. RK and AAL contributed by imposing the experiment and helped edit, summarise and revise the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None.

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