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Transforming growth: exposing the effects of salicylic acid and hydrogel (SAP) on mustard crops for increased yield and sturdiness

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Abstract

The dry and semi-arid regions of the Indo-Gangetic plains have significant water-related difficulties. *Brassica juncea*, often known as mustard, is a resilient crop that flourishes during the rabi season and requires a reduced amount of water in comparison to other crops. A research study was conducted during the *rabi* season of 2020-21 to evaluate the effects of hydrogel SAP (Super Absorbent Polymer) and foliar spray of salicylic acid on different development stages of mustard crop. Based on research findings, the utilization of hydrogel @ 5.0 kg/ha, in conjunction with a foliar application of salicylic acid 200 ppm concentration, throughout the flowering and siliqua formation phases, had a significant impact on several yield characteristics. The aforementioned characteristics encompass seed yield (2613 kg/ha), stover yield (5435 kg/ha), soil moisture content (23.59%), relative water content in leaves, protein content and yield, SPAD value, proline, and NR B:C ratio (1.59). The utilization of hydrogel and salicylic acid has the potential to enhance the sustainable and efficient production and profitability of mustard crops in the arid and semi-arid regions of Haryana state of India.

Keywords: *Hydrogel, mustard, RWC, salicylic acid, soil moisture content*

Introduction

In agriculture, searching for new and sustainable techniques is crucial to guarantee global food security in a constantly changing environment. Mustard crops, renowned for their adaptability and importance across several sectors, are subject to the requirements of contemporary agriculture. A potential combination arises at the crossroads of agricultural science and technology - hydrogel and salicylic acid. This study aims to reveal the significant effect of these two compounds on mustard crops, namely in increasing yield and enhancing resilience.

Oil seeds rank as the second largest commodity in the Indian agricultural sector, behind grains. The rapeseed - mustard oil seed families have significant importance due to their widespread usage as cooking ingredients in several nations, with a particular emphasis on their stability in India. India's edible oil output is at 10.52 MT, insufficient to meet the increasing demand in the country. India imports around 50 to 60% of its total edible oil usage annually, incurring significant foreign exchange costs. In the fiscal year 2020-21, India imported 13.45 million metric tons of edible oil, valued at Rs 82,123 crores (Anonymous, 2021). India is projected to need 29-34 million metric tons of vegetable oils and 82-102 million metric tons of oilseeds by 2030 to satisfy the increasing population demand (Chauhan *et al*., 2020). In the 2022-23 period, the mustard crop occupied an area of 8,842 thousand hectares and yielded an output of 12.82 metric tons. Additionally, the overall production of edible oilseeds amounted to 40.0 metric tons. This indicates that mustard plays a crucial role in supplying the country's demand for edible oil (Anonymous, 2024). According to Shweta *et al*. (2023), the cultivation of this crop in Haryana spans an area of 4.2 lakh hectares, with an output of 6.9 lakh tons and a productivity of 1609 kg/ha.

The cultivation of mustard in India mostly relies on rainfed or restricted irrigation systems, resulting in low yields of both seeds and oil. During crucial periods of agricultural growth, the crop frequently encounters drought-like conditions. Therefore, it is crucial to ascertain strategies for maintaining production while mitigating the effects of water stress throughout active crop growth. Utilizing chemicals to save and efficiently utilize soil moisture in the root zone would undoubtedly enhance crop output in water-limited conditions.

Hydrogel, a polymer with the ability to absorb and release moisture, is increasingly being acknowledged for its potential to revolutionize irrigation techniques and mitigate water stress in crops (Malik *et al*., 2023; Shweta *et al*., 2022). Hydrogel use has the potential to effectively preserve soil moisture and greatly enhance crop output. According to Kalhapure *et al*. (2016), there is significant potential for these substances to enhance the physico-chemical and biological characteristics of the soil. Research has indicated that the implementation of SAP has the potential to enhance soil structure (Yang *et al*., 2021), as well as increase organic carbon and chemical characteristics, and optimize nutrient use efficiency (Tian *et al*., 2019).

The naturally occurring plant hormone salicylic acid is recognized for its capacity to enhance stress tolerance and fortify defence mechanisms in plants. According to Nasrin *et al*. (2014), it has a significant impact on several aspects of plant development, such as growth, photosynthesis, transpiration, ion uptake, and transport. The primary function of this entity is to facilitate osmotic adjustment, a physiological mechanism that aids in the regulation of intracellular water balance and therefore limits cellular water loss. Nazar and Sareer (2015) suggested that the introduction of SA into plants under drought environments has an impact on the redox equilibrium, ethylene synthesis inhibited, facilitating photosynthesis and stomatal conductance.

The amalgamation of these two facets presents a thrilling prospect to usher in a novel era of agricultural techniques.The objective of this study is to investigate the molecular mechanisms, physiological responses, and agricultural implications resulting from the interplay of hydrogel, salicylic acid, and mustard crops. The primary aim of this study is to offer significant insights that might potentially contribute to the development of sustainable agricultural practices, therefore, improving both the productivity and resilience of mustard crops in the face of environmental challenges. In this study, we want to examine the untapped potential of salicylic acid and hydrogel in regulating the growing conditions of mustard.

Materials and Methods

The experiment was carried out at the Oil Seed Section, Department of Genetics & Plant Breeding, CCS Haryana Agricultural University, Hisar, Haryana during the *rabi* seasons in the consecutive years of 2020-21.The place is situated at coordinates 29°10' N latitude, 75° 46' E longitude, and has an elevation of 215.2 m above mean sea level. The climate of Hisar is semi-arid, characterized by a harsh cold in winter and hot, dry, and drying winds in summer. During the hot summer months of May and June, the maximum temperature reaches around 45°C. Conversely, in the winter months of December and January, the lowest temperature can reach subzero levels. The region experiences an annual precipitation of around 450 mm, with 70-80 per cent occurring during the monsoon period from July to September. The remaining rainfall is obtained in the form of cyclic rain showers during the winter and spring seasons. From July to March, the average relative humidity is relatively stable at around 75 to 90 per cent. However, it gradually declines in April and maintains around 40-50 per cent during the hot summer months of May and June. The experimental field consisted of sandy loam soil with a slightly alkaline pH of 8.0. The soil organic carbon content was low at 0.39%, while the accessible nitrogen content was low at 178 kg/ha. The P_2O_5 content was medium at 12.7 kg/ha, while the K_2O and S content were high at 332 kg/ha and 28 ppm, respectively.

The experiment consisted of 12 treatments with thrice replication in a Complete Randomization Design. Treatments consist of soil application hydrogel with different rates, salicylic acid spray and a combination of hydrogel and salicylic acid. The treatments are T_1: control, T_2: hydrogel @ 2.5 kg/ha, T_3: hydrogel @ 3.75 kg/ha T_4: hydrogel @ 5 kg/ha, T_5: salicylic acid @100 ppm at flowering and siliqua formation, T_6: salicylic acid @ 200 ppm at flowering and siliqua formation, T_7: hydrogel @ 2.5 kg/ha withsalicylic acid @100 ppm at flowering and siliqua formation, T_8: hydrogel @ 2.5 kg/ha with salicylic acid @ 200 ppm at flowering and siliqua formation, T_9: hydrogel @ 3.75 kg/ha with salicylic acid @100 ppm at flowering and siliqua formation, T_{10}: hydrogel @ 3.75 kg/ ha with salicylic acid @ 200 ppm at flowering and siliqua formation T_{11}: hydrogel @5 kg/ha with salicylic acid @100 ppm at flowering and siliqua formation, T_{12}: hydrogel @ 5 kg/ha with salicylic acid @ 200 ppm at flowering and siliqua formation. The mustard variety RH-725 was sown in the first fortnight of October during an experiment with uniform application of a recommended dose of fertilizer 80:30:20 kg NPK ha^{-1}. Half the dose of nitrogen along with the full dose of phosphorus and potassium were applied as basal and the remaining half dose of nitrogen was top dressed after first irrigation 30-35 days after sowing. To maintain the proper plant population sowing was done at row-to-row spacing at 30 cm and plant-to-plant distance was maintained at 10-15 cm through thinning operation at 20 days after sowing. All the inter-cultivation practices were done in all the treatments similarly. To improve water retention and optimize soil conditions, a comprehensive mixture of hydrogel was applied to the soil before seeding. A small quantity of ethanol was combined with salicylic acid to facilitate its dissolution, followed by the addition of this resulting aqueous combination to water (Mahto *et al*., 2023**)**. The solution was sprayed onto the leaves using a knapsack sprayer during the Flowering and siliqua formation phases as per the treatments.

The crop was physically picked annually at the level of physiological maturity. The calculation of soil moisture and water usage efficiency (WUE) was performed using a conventional method. Under established statistical protocols, the growth, yield qualities, and seed yield were determined. The calculation of gross and net returns was performed by considering the seed and straw yield, as well as the current market values of mustard throughout the four seasons. To get the benefit-to-cost ratio, the net returns were divided by the overall cultivation cost. Statistical analysis was conducted on the data, and the findings of the pooled analysis are provided.

Parametric measurements were obtained using the following approaches.

The calculating approach employed by Shweta *et al*. (2021 and 2022) was utilised to determine the relative water content in the topmost leaf during the morning hours.

$RWC = (FW\text{-}DW/TW\text{-}DW) \times 100$

The quantification of chlorophyll in the leaf was conducted with a CCM (SPAD-502). Excised leaf water loss(g/g) was determined by employing the subsequent equation:

ELWL= (Fresh Wt. - Wilted Wt.) /Dry Wt

The determination of proline content was conducted by employing a standard curve that relied on measurements of fresh weight. The formula for proline (μmoles/g) is calculated as follows:

proline (μg/ml) = {proline (μg/ml) × (toluene used ml)/ 115.5μg/μmoles}/(g sample/5)

The calculation of protein content in the seed was determined using the formula

Protein content = Nitrogen content × 6.25.

Correlation coefficients were conducted among many variables. The study employed linear regression analysis to examine the association between grain yield, protein yield, and SPAD value. The equation may be expressed as follows:

$Y = a + bX1 + cX2$.

Mustard growth, yield and parametric data were all subjected to a two-way analysis of variance (ANOVA). We utilized OPSTAT to check if the changes in the means were statistically significant at the 5% probability level.

Results and Discussion

Effect on mustard growth and yield attributes

The data indicated a substantial impact on the growth characteristics of mustard compared to the control group. The treatment involves applying hydrogel @ 5.0 kg/ha to the soil and salicylic at 200 ppm/ha during the flowering and siliqua formation stages. This treatment leads to a significant increase in plant height (248.33 cm), dry matter accumulation per pant (24.62 g per plant), primary branches (6.43), secondary branches (10.93), and main shoot length (92.0 cm) compared to the other treatments. The growth study involved hydrogel soil application @ 5.0 kg/ha and salicylic acid at a concentration of 100 ppm/ ha during the flowering and siliqua formation stages. Additionally, hydrogel @ 3.75 kg/ha combined with salicylic acid at a concentration of 200 ppm/ha, hydrogel @ 3.75 kg/ha combined with salicylic acid at a concentration of 100 ppm/ha, hydrogel @ 2.5 kg/ha with a concentration of 200 ppm/ha, and hydrogel @ 2.5 kg/ha with a concentration of 100 ppm/ha were also applied during the flowering and siliqua formation stages. In terms of plant height, dry matter accumulation, primary branches, and secondary branches, both treatments exhibit statistical parity. The application of hydrogel or salicylic acid resulted in a significant increase in dry matter accumulation per plant compared to the control group. The observed phenomenon may be linked to the utilization of hydrogel, which possesses moisture-retaining properties that aid in the preservation of soil moisture inside the rhizosphere for an extended period. This, in turn, facilitates the availability of nutrients and ultimately enhances crucial physiological processes. The use of salicylic acid spray is of significant importance in facilitating the growth and holistic development of mustard crops. As substantiated by Kavita *et al*., 2022 and Kumawat *et al*. (2024).

The hydrogel soil application and salicylic acid foliar spray had a substantial impact on the total number of siliqua per plant, as shown in Table 2. During the blooming and siliqua formation stages, the hydrogel application @ 5 kg/ha, along with 200 ppm salicylic acid concentration, resulted in a notable increase in the number of siliquae per plant (433.3) and seeds per siliqua (16.27) compared to both the control group and the other treatments. Meena *et al*. (2020), Mahto *et al.* (2023), and Kumawat *et al.* (2024) have also documented the beneficial influence of hydrogel and salicylic acid foliar spray on the quantity of siliqua per plant and seeds per siliqua in mustard. Pusa hydrogel functions as a moisture-retaining agent, and its controlled release aids in preserving soil moisture until the crop reaches maturity.

Effect of hydrogel and salicylic acid on seed yield and SMC (%)

The soil application of hydrogel @ 5.0 kg/ha, along with

Table 1: Effect of hydrogel (SAP) and salicylic acid on growth and yield attributing characters of mustard

Treatment details	Plant height at harvest (cm)	DMA/pl (g)	Primary branches	Sec. branches	Main shoot length (cm)
T_1: Control	196.33	20.00	4.23	5.70	73.33
T_2: hydrogel @ 2.5 kg/ha	198.33	22.09	4.60	6.60	75.00
T_3: hydrogel @ 3.75 kg/ha	212.00	21.86	4.93	7.27	78.00
T_4: hydrogel @ 5.0 kg ha	215.33	20.57	5.07	7.50	79.67
T_5: SA @ 100 ppm/ha at F and SF stage	205.33	22.13	5.13	8.33	82.33
T_6: SA @ 200 ppm/ha at F and SF stage	210.00	22.64	5.23	8.50	83.67
T_7: hydrogel @ 2.5 kg/ha+ SA @ 100 ppm/ha at F and SF stage	224.00	23.25	5.40	8.73	83.67
T_8: hydrogel @ 2.5 kg/ha+ SA @ 200 ppm/ha at F and SF stage	223.00	23.43	5.50	9.37	84.00
T_9: hydrogel @ 3.75 kg/ha+ SA @ 100 ppm/ha at F and SF stage	225.00	23.53	5.73	9.57	88.33
T_{10}: hydrogel @ 3.75 kg/ha+ SA @ 200 ppm/ha at F and SF stage	227.00	23.85	5.93	9.67	89.00
T_{11}: hydrogel @ 5.0 kg/ha+ SA @ 100 ppm/ha at F and SF stage	238.00	24.09	6.03	10.17	90.33
T_{12}: hydrogel @ 5.0 kg/ha+ SA @ 200 ppm/ha at F and SF stage	248.33	24.62	6.43	10.93	92.00
C. D. (p=0.05)	21.47	0.95	1.17	2.16	9.73

Table 2 : Effect of hydrogel and salicylic acid on mustard seed and stover yield, and soil moisture content (SMC) after harvesting

Treatment details	Total siliqua/plant	Seeds /pod	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})	SMC (%)
T_1: Control	200.67	12.53	2,067	4,527	15.23
T_2: hydrogel @ 2.5 kg/ha	221.33	13.80	2,213	4,537	21.85
T_3: hydrogel @ 3.75 kg/ha	241.00	13.40	2,095	3,959	23.25
T_4: hydrogel @ 5.0 kg ha	259.00	13.33	2,095	4,399	24.47
T_5: SA @ 100 ppm/ha at F and SF stage	267.67	14.00	2,274	4,230	15.01
T_6: SA @ 200 ppm/ha at F and SF stage	323.33	14.00	2,382	4,502	14.87
T_7: hydrogel @ 2.5 kg/ha+ SA @ 100 ppm/ha at F and SF stage	324.67	14.40	2,165	4,330	21.42
T_8: hydrogel @ 2.5 kg/ha+ SA @ 200 ppm/ha at F and SF stage	340.33	14.47	2,267	4,693	21.2
T_9: hydrogel @ 3.75 kg/ha+ SA @ 100 ppm/ha at F and SF stage	354.33	14.53	2,418	4,933	20.87
T_{10}: hydrogel @ 3.75 kg/ha+ SA @ 200 ppm/ha at F and SF stage	386.67	14.80	2,135	4,398	20.6
T_{11}: hydrogel @ 5.0 kg/ha+ SA @ 100 ppm/ha at F and SF stage	390.00	15.07	2,256	4,715	23.45
T_{12}: hydrogel @ 5.0 kg/ha+ SA @ 200 ppm/ha at F and SF stage	433.33	16.27	2,613	5,435	23.59
C. D. (p=0.05)	36.80	1.51	96	199	-

200 ppmsalicylic acid concentration treatment exhibited significantly higher seed yield (2613 kg/ha), and stover yield (5435 kg/ha) over other treatments (Table 2). Seed yield was 26.42% higher than control and stover yield was 20.06 % higher than control. Kumawat *et al.* (2024) assert that the observed augmentation in crop output and diverse characteristics may be ascribed to the expanded accessibility of water and the better provision of nutrients permitted by the utilization of hydrogel (Rathore *et al*., 2019). In addition, the use of salicylic acid spray under stressful conditions was found to promote the translocation of photosynthesis towards reproductive organs by mitigating stress promoting cell division and inhibiting ethylene production (Tirani *et al.,* 2013; Nazar & Sareer 2015).

Soil moisture content (%) at harvest maximum was arrived in soil application of hydrogel @ 5 kg/ha, along with salicylic acid at a concentration of 200 ppm treatment (23.59 %). The application of only salicylic acid does not have any positive effect on soil moisture content, while only hydrogel application also improves soil moisture content.

Effect on quality and photosynthesis activity

The hydrogel treatment at a rate @ 5 kg/ha, combined with salicylic acid treatment @ of 200 ppm concentration, resulted in the greatest protein content (18.7) and protein production (488.6 kg/ha). The use of hydrogel as soil application @ 5.0 kg/ha, along with salicylic acid 200 ppm concentration, resulted in a 10% increase in protein content and a 39% increase in protein production compared to the control group. Applying hydrogel and salicylic acid separately at varying doses results in enhanced protein production as compared to the control. The concurrent utilization of hydrogel and salicylic acid resulted in the establishment of a more advantageous nutritional milieu within the soil and plant system, hence facilitating a more conducive nutritional environment for both entities.

High chlorophyll content indicates a low degree of photo-inhibition and reduces carbohydrate losses for grain development. Foliar leaf chlorophyll content of leaf is an indicator of the photosynthesis of plants. Mustard crop under soil application of hydrogel @ 5.0 kg/ha, along with salicylic acid 200 ppm concentration possessed maximum SPAD chlorophyll and were about 30.32% higher than that of control. Application of hydrogel (2.5, 3.75 and 5.0 kg/ha) and salicylic acid (100 and 200 ppm) alone also improve the SPAD chlorophyll over control. There is also a positive relation between seed yield and SPAD value (Table 3).

Table 3: Effect of hydrogel and salicylic acid on mustard physiological and quality parameters

Treatments	Protein content (%)	Protein yield	SPAD	Proline (imole/g DW)	ELWL	RWC (%) of leaves	
						Flowering	Siliqua
T_1 : Control	17	351.4	40.17	184.9	49.0	77.61	88.67
T_2 : hydrogel @ 2.5 kg/ha	17.4	385.1	46.48	183.6	46.5	79.23	90.96
T_3 : hydrogel @ 3.75 kg/ha	17.6	368.7	47.89	174.4	44.0	81.31	91.04
T_4 : hydrogel @ 5.0 kg ha	17.7	370.8	48.45	171.7	42.5	87.48	91.21
T_5 : SA @ 100 ppm/ha at F and SF stage	17.5	398.0	50.06	169.8	41.7	83.22	92.17
T_6 : SA @ 200 ppm/ha at F and SF stage	17.9	426.4	50.12	165.6	41.3	83.41	92.29
T_7 : hydrogel @ 2.5 kg/ha+ SA @ 100 ppm/ha at F and SF stage	18.1	391.9	50.21	161.4	40.3	81.47	92.39
T_8 : hydrogel @ 2.5 kg/ha+ SA @ 200 ppm/ha at F and SF stage	18.3	414.9	50.48	155.7	40.5	87.26	92.13
T_9 : hydrogel @ 3.75 kg/ha+ SA @ 100 ppm/ha at F and SF stage	18.3	442.5	51.26	142.6	39.3	88.32	92.11
T_{10} : hydrogel @ 3.75 kg/ha+ SA @ 200 ppm/ha at F and SF stage	18.5	395.0	51.48	135.7	38.1	89.78	92.67
T_{11} : hydrogel @ 5.0 kg/ha+ SA @ 100 ppm/ha at F and SF stage	18.6	419.6	51.90	121.5	37.4	93.33	93.78
T_{12} : hydrogel @ 5.0 kg/ha+ SA @ 200 ppm/ha at F and SF stage	18.7	488.6	52.35	115.6	36.5	93.77	94.42
C.D. (p=0.05)	0.8	21.6	2.4	7.8	2.1	3.9	NS

Different treatments of hydrogel and salicylic acid significantly influenced proline content and Proline content in the mustard leaves was significantly lower in control (115.6 ìmole/g DW) and highest (184.9 ìmole/g DW) proline content with hydrogel @ 5.0 kg/ha, along with salicylic acid 200 ppm concentration (Table 3).The individual hydrogel soil application and salicylic acid, and their combined implement fostered a more favourable nutritional environment within both the soil and plant system. Consequently, this led to a significant enhancement in oil yield protein content, SPAD chlorophyll and RWC. RWC at flowering was significantly affected by the treatments and a non-significant effect of treatments was observed at the siliqua stage.

Effect on economics

The results of a comparative economic analysis revealed that the use ofhydrogel @ 5.0 kg/ha combined with 200 ppm of salicylic acid during the flowering and siliqua formation stages yielded the maximum gross returns (Rs 141870/ha) and net returns (Rs 87081/ha). The application of 5.0 kg/ha of hydrogel in combination with 200 ppm of salicylic acid during the flowering and siliqua formation stages resulted in a higher net return of Rs 22639/ha compared to the control group. This was closely followed by the application of 200 ppm of salicylic acid during the flowering and siliqua formation stages, which yielded a profit of ¹ 15312/ha compared to the control group. The soil application of hydrogel @ 5.0 kg/ha mixed with 200 ppm of salicylic acid throughout the blooming and siliqua formation stages resulted in a maximum increase of 35.13% in profits compared to the control group.

Correlation and regression

The data presented in Table 5 pertains to the link between seed yield and various yield variables as well as physiological indicators. The study observed significant and positive correlations between primary branches (r=0.649), secondary branches (r=0.686), main shoot length (r=0.656), siliqua per plant (r=0.662), seeds/siliqua (r=0.727), and dry matter accumulation per plant (r=0.661) with grain yield (see Figure 1a&b). However, no significant correlations were found between plant height (r=0.571), oil content (r=-0.065), and proline yield with grain yield. There was a negative correlation observed between grain yield and stover yield (-0.626), and proline yield (-0.361). Simultaneously, there was a substantial and positive correlation between physiological indicators such as protein production and SAPD, and grain yield.

The research findings indicate that the soil application of

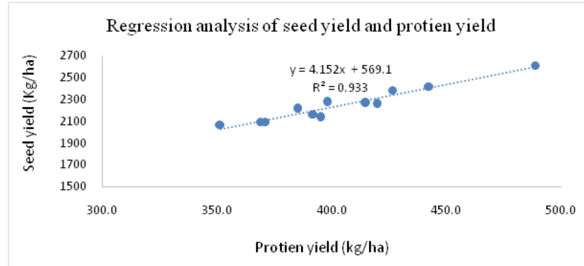
Table 4 : Effect of hydrogel and salicylic acid on mustard economics

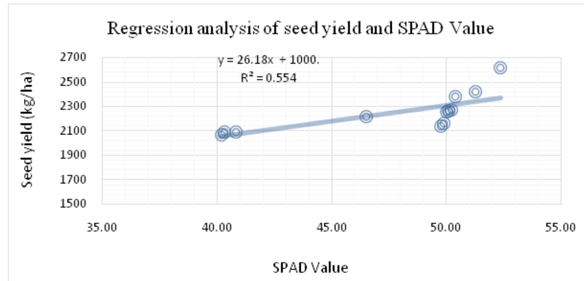
Treatments	COC	GR	NR	B:C
T_1 : Control	48293	112735	64442	1.33
T_2 : hydrogel @ 2.5 kg/ha	50793	120526	69733	1.37
T_3 : hydrogel @ 3.75 kg/ha	52043	114211	62168	1.19
T_4 : hydrogel @ 5.0 kg ha	53293	114211	60918	1.14
T_5 : SA @ 100 ppm/ha at F and SF stage	49641	123781	74140	1.49
T_6 : SA @ 200 ppm/ha at F and SF stage	49789	129544	79754	1.60
T_7 : hydrogel @ 2.5 kg/ha+ SA @ 100 ppm/ha at F and SF stage	52141	117964	65823	1.26
T_8 : hydrogel @ 2.5 kg/ha+ SA @ 200 ppm/ha at F and SF stage	52289	123389	71100	1.36
T_9 : hydrogel @ 3.75 kg/ha+ SA @ 100 ppm/ha at F and SF stage	53391	131464	78073	1.46
T_{10} : hydrogel @ 3.75 kg/ha+ SA @ 200 ppm/ha at F and SF stage	53539	116364	62825	1.17
T_{11} : hydrogel @ 5.0 kg/ha+ SA @ 100 ppm/ha at F and SF stage	54641	122820	68179	1.25
T_{12} : hydrogel @ 5.0 kg/ha+ SA @ 200 ppm/ha at F and SF stage	54789	141870	87081	1.59

Table 5: Correlation of the mustard seed yield with yield attributes and physiological parameters

	Seed Yield	Plant Height	Primary Branches	Secondary Branches	Shoot Height	Siliqua /plant	Seed /siliqua	Dry Matter Accumulation	Stover Yield	Protien Yield	SPAD	Proline Yield	ELWL
Seed Yield	1												
Plant Height	0.571^{NS}	1											
Primary Branches	0.649*	0.956**	1										
Secondary Branches	0.686*	0.921**	0.985**	1									
Shoot Height	0.656*	0.910**	0.983**	0.984**	1								
Silliqa/plant	0.662*	0.930**	0.979**	0.977**	0.978**	1							
Seed/siliqua	0.727**	0.945**	0.976**	0.963**	0.940**	0.952**	1						
Dry Matter Accumulation	0.661*	0.830**	0.904**	0.925**	0.894**	0.916**	0.891**	1					
StoverYield	-0.626*	-0.544^{NS}	-0.480^{NS}	-0.418^{NS}	-0.382^{NS}	-0.437^{NS}	-0.614*	-0.367^{NS}	1				
ProtienYield	0.729**	0.614*	0.556^{NS}	0.504^{NS}	0.471^{NS}	0.531^{NS}	0.686*	0.449^{NS}	-0.979**	1			
SPAD	0.727**	0.622*	0.564^{NS}	0.512^{NS}	0.478^{NS}	0.537^{NS}	0.694*	0.456^{NS}	-0.981**	1.000**	1		
Proline Yield	-0.361^{NS}	-0.073^{NS}	0.036^{NS}	0.109^{NS}	0.139^{NS}	0.067^{NS}	-0.127^{NS}	0.109^{NS}	0.835**	-0.800**	-0.795**	1	
ELWL	0.694*	0.547^{NS}	0.480^{NS}	0.425^{NS}	0.389^{NS}	0.454^{NS}	0.621*	0.382^{NS}	-0.983**	0.996**	0.995**	-0.852**	1

Note: * significant at 5 %, ** significant at 1 % and ^{NS}= Non-significant, ELWL = Excised Leaf Water Loss





hydrogel @ 5.0 kg/ha, followed by a foliar spray of salicylic acid @ 200 ppm concentration during the flowering and siliqua formation stages, had a notable effect on various yield attributes. These attributes include seed yield (2613 kg/ha), stover yield (5435 kg/ha), soil moisture content (23.59%), relative water content in leaves, protein content and yield, SPAD value, proline, and NR 7 B:C ratio (1.59). Hydrogel and salicylic acid can be used to improve the production and profitability of mustard crops in the arid and semi-arid regions of Haryana sustainably and effectively.

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