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Maximizing productivity, profitability and water use efficiency in Indian mustard (*Brassica juncea*) through hydrogel and salicylic acid

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ABSTRACT

Addressing water scarcity in the arid and semi-arid regions of Rajasthan presents a substantial challenge to improve the productivity of Indian mustard [*Brassica juncea* (L.) Czern.]. The limited availability of water in these areas results in reduced yields of Indian mustard. Therefore, a field experiment was conducted during *rabi* (winter) seasons of 2018–19, 2019–20 and 2020–21 at the research farm of Sri Karan Narendra Agriculture University, Jobner, Rajasthan, to evaluate the impact of hydrogel and foliar application of salicylic acid on the growth, yield, economic returns and water use efficiency of Indian mustard. The results revealed that the application of hydrogel at a rate of 5.0 kg/ha, in combination with salicylic acid at a concentration of 200 ppm during the flowering and siliqua formation stages through foliar spray, had a significant and highly effective impact. This treatment displayed superior performance across a range of parameters, including growth characteristics, yield attributes, seed yield (1840 kg/ha), stover yield (3847 kg/ha), water use efficiency (8.53 kg/ha-mm), protein content (18.6%), oil content (39.13%), net returns (₹51,710/ha) and benefit-cost ratio (2.03). Furthermore, treatments involved 5.0 kg/ha of hydrogel in conjunction with 100 ppm of salicylic acid, as well as 2.5 kg/ha of hydrogel with 200 ppm of salicylic acid, produced similar results. The combined findings of this experiment endorse the application of hydrogel and salicylic acid as a sustainable and effective strategy for enhancing the productivity, profitability and water use efficiency of Indian mustard in the arid and semi-arid regions of Rajasthan.

Keywords: Hydrogel, Mustard, Salicylic acid, Water use efficiency, Yield

Indian mustard [*Brassica juncea* (L.) Czern.] stands as a pivotal winter (*rabi*) season oilseed crop in India which gives edible oil widely utilized as a cooking medium in north India. Rajasthan holds the first position in both the cultivated area and production of rapeseed and mustard in India (Anonymous 2022). Despite the prominence of this major oilseed crop in the state, its productivity lags significantly behind its achievable yield potential. The avenue for achieving this improvement lays in the adoption of innovative crop production technologies. The important constraints of low productivity of mustard are primarily water stress and other biotic and abiotic stresses. A critical concern arises from the inadequate soil moisture conservation in the sandy soils of semi-arid regions in Rajasthan, where replenishment of the crop water need is not sufficient. This insufficiency leads to moisture stress during the active growth period, significantly hampering the crop's development. In this context, the introduction of 'Hydrogel' stands out as a groundbreaking solution. Hydrogel, characterized as an insoluble, cross-linked three-dimensional polymer, has the ability to absorb water exceeding 400 times its own weight. It exhibits a gradual release of absorbed water, coupled with the additional benefit of enhancing various hydro-physical properties of the soil. Anupama and Parmar (2012) had showed significant enhancement in yield and water use efficiency of many crops by applying hydrogel.

Salicylic acid, a naturally-occurring phenolic phytohormone, plays a pivotal role in plant physiology. It exerts influence over several facets of plant development, including growth, photosynthesis, transpiration, ion uptake and transport (Nasrin *et al*. 2014). It contributes to tolerance against drought, chilling, heat and osmotic stress. Its major role is in facilitating osmotic adjustment, a process that helps regulate the balance of water within cells and, consequently, restricts water loss from these cells. The combined application of hydrogel and salicylic acid emerges as a promising management practice to enhance the productivity of mustard amid water scarcity challenges. In light of the aforementioned factors, present study was carried out to evaluate the impact of hydrogel and salicylic

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acid on optimizing the productivity, economic returns and water use efficiency of Indian mustard.

MATERIALS AND METHODS

A field experiment was conducted during winter (*rabi*) seasons of 2018–19, 2019–20 and 2020–21 at the research farm of Sri Karan Narendra Agriculture University, Jobner [26°05' N; 75°28' E; altitude of 427 meters amsl], Rajasthan. This location falls within agro-climatic zone III A, characterized as a semi-arid eastern plain zone in Rajasthan. The climate of this region is distinctly semi-arid, marked by significant temperature fluctuations throughout the year. Summers experience high temperatures, occasionally reaching up to 48°C, while winters witness a sharp temperature drop, with lows as cold as -1.0°C. Frost events are not uncommon during the winter season. The soil in the experimental field is classified as loamy sand and possesses low organic carbon content (0.23%). The soil samples were drawn from top 15 cm soil depth. It contains 135.8 kg/ha of available nitrogen (N), 16.5 kg/ha of available phosphorus (P), and a medium level of available potassium (K) at 149.6 kg/ha. Our study encompassed 9 treatment combinations, viz. T_1, Control; T_2, Hydrogel application at 2.5 kg/ha; T_3, 5.0 kg/ha; T_4, Salicylic acid application at 100 ppm during the flowering and siliqua formation stages; T_5, Salicylic acid application at 200 ppm during the same stages; T_6, Hydrogel at 2.5 kg/ha combined with salicylic acid at 100 ppm; T_7, Hydrogel at 2.5 kg/ha combined with salicylic acid at 200 ppm; T_8, Hydrogel at 5.0 kg/ha combined with salicylic acid at 100 ppm; and T_9, Hydrogel at 5.0 kg/ha combined with salicylic acid at 200 ppm. These treatments were assessed using a randomized block design (RBD) with 3 replications, each occupying a gross plot size of 5.0×3.6 m^2. Mustard variety NRCHB 101 was selected for the experiment and a recommended basal dose of 60 kg of nitrogen (N) and 40 kg of phosphorus (P_2O_5) per hectare through urea and diammonium phosphate (DAP) was applied before sowing. To enhance water retention and optimize soil conditions, hydrogel was thoroughly mixed with the soil and applied to the designated experimental plots within furrows just before sowing. Salicylic acid was administered through foliar spray during the flowering and siliqua formation stages, following the treatment plan. For sowing the crop, a row-to-row spacing of 30 cm and a plant-to-plant distance of 10 cm was maintained, utilizing a seed rate of 4 kg/ha. Thinning operations were conducted at 20 days after sowing (DAS) to ensure a proper plant stand. Subsequently, manual hoeing and weeding were carried out at 35 DAS to enhance aeration and remove weeds. The cultivation practices followed the recommended agronomic guidelines of the zone.

During the harvest phase, a meticulous sampling process involved selecting five plants from each designated plot. These plants were carefully tagged for subsequent measurements, encompassing crucial parameters such as plant height, number of branches/plant, siliqua/plant and seeds/siliqua. To assess dry matter accumulation at the time of harvest, plants from 1 m row were randomly uprooted. After root removal, the samples were air-dried for several days and subsequently dried in an electric oven at 70°C until they reached a consistent weight. The recorded weight was then presented as the average dry matter accumulation per metre of the row (in grams). Upon reaching maturity, the main plots were harvested and the harvested material underwent a complete sun-drying process. The weight of the sun-dried harvest from each plot was individually recorded before commencing the threshing process. This weight is referred to as the biological yield. Following the threshing, cleaning and drying procedures were meticulously carried out to obtain the seed yield. For a thorough assessment, the economic considerations of the various treatments were analyzed by considering the input costs and the revenue generated from the output at the current market prices. Water-use efficiency (WUE) was calculated using the formula provided by Viets (1966) and expressed as kg/ha-mm:

$$\text{WUE} = \frac{\text{Seed yield (kg/ha)}}{\text{Actual Evapo-transpiration (mm)}}$$

Protein content in the seed was determined by multiplying the nitrogen content in the seed by the factor 6.25. The oil content in mustard seed was assessed using a Soxhlet apparatus with petroleum ether (60–80°C) as an extractant, following the method outlined in the A.O.A.C. (1960). The experimental data were subjected to statistical analysis employing standard techniques of analysis of variance (ANOVA). Pooled analysis of the data was conducted, adhering to the methodology outlined by Gomez and Gomez (1984). Furthermore, mean comparison was carried out based on critical differences at the 5% probability level.

RESULTS AND DISCUSSION

Growth parameters: The pooled data of three years (Table 1) showed that all the treatments exhibited significant

Table 1 Effect of hydrogel and salicylic acid on growth parameters of Indian mustard at harvest (Pooled data of three years)

Treatment	Plant height (cm)	Branches/plant		Dry matter (g/m row length)
		Primary	Secondary	
T_1	155.3	5.18	9.52	190.0
T_2	172.8	6.20	10.4	208.7
T_3	177.4	6.32	10.8	216.3
T_4	171.1	6.22	10.3	205.7
T_5	175.7	6.37	10.7	211.7
T_6	185.3	6.84	12.9	228.3
T_7	187.2	6.94	13.2	230.7
T_8	193.1	7.17	13.5	240.0
T_9	196.0	7.60	13.7	244.0
SEm±	3.59	0.14	0.23	5.01
CD (P=0.05)	10.78	0.42	0.71	15.02

Treatment details are given under Materials and Methods.

effect on enhancing the growth parameters of Indian mustard over control. The treatment involving the application of 5.0 kg/ha of hydrogel and 200 ppm of salicylic acid during the flowering and siliqua formation stages significantly resulted in the tallest plant height (196.0 cm), the highest dry matter production (244.0 g/m of row length), and the most primary branches (7.60) and secondary branches per plant (13.7) among all the treatments. It's worth noting that the treatments applying 5.0 kg/ha of hydrogel and 100 ppm of salicylic acid during the flowering and siliqua formation stages, as well as the treatment of 2.5 kg/ha of hydrogel and 200 ppm of salicylic acid during the same stages, exhibited similar performance in these aspects. The observed similarities in the mentioned parameters suggest that these treatments were statistically equivalent in promoting plant height, dry matter accumulation and the development of primary and secondary/plant. Additionally, single application of hydrogel 5.0 kg/ha and 2.5 kg/ha, as well as salicylic acid at 200 ppm and 100 ppm exhibited a substantial increase in plant height, primary and secondary branches/plant and dry matter accumulation of mustard over control. The improvement in growth attributes of Indian mustard with application of hydrogel can be attributed to its moisture-retaining capabilities, thereby sustaining optimal soil moisture levels in the rhizosphere for an extended duration, fostering nutrient availability and, subsequently, promoting essential physiological processes that drive plant growth (Anupama *et al*. 2005). Foliar spray of salicylic acid played a crucial role in increasing plant height, branching and overall development of crop. The findings from the present experiment also align closely with the outcomes reported by Sharma *et al.* (2017) who revealed that application of salicylic acid to mustard crop significantly increased growth parameters. Further, results of the present study are also supported by earlier findings obtained by Jat *et al*. (2018).

Yield attributes, yield and water use efficiency (WUE): The application of hydrogel at 5.0 kg/ha, along with salicylic acid at a concentration of 200 ppm during the flowering and siliqua formation stages, resulted in the highest number of siliqua per plant (223.0), seeds per siliqua (14.2), and maximum test weight (4.42). This outcome was significantly superior to the control, as well as treatments involving hydrogel at 2.5 kg/ha, and at 5.0 kg/ha and salicylic acid at 200 ppm and at 100 ppm. Moreover, it was statistically on par with the treatments hydrogel at 5.0 kg/ha + salicylic acid at 100 ppm and hydrogel at 2.5 kg/ha + salicylic acid at 200 ppm (Table 2). Additionally, this particular treatment exhibited the highest seed yield (1840 kg/ha) and stover yield (3847 kg/ha). However, it shared statistical similarity with the treatment hydrogel at 5.0 kg/ha + salicylic acid at 100 ppm during the flowering and siliqua formation stages, as well as with the treatment hydrogel at 2.5 kg/ha + salicylic acid at 200 ppm during the same stages in this respect. Notably, these three treatments collectively improved the seed yield by 46.14%, 43.84% and 36.13% over the control, respectively. The increased yields and various yield-related attributes observed in these treatments can be attributed to the enhanced water availability and indirectly, improved nutrient supply facilitated by the application of hydrogel under conditions of water stress. This, in turn, contributed to improved translocation of water, nutrients, and photosynthates, ultimately resulting in enhanced yield (El Hady *et al*. 2006). According to Singh *et al*. (2017) application of hydrogel at 5.0 kg/ha recorded maximum number of siliqua/plant and 1000-seed weight of Indian mustard. Additionally, the increased yield of mustard in present study due to foliar spray of salicylic acid might be attributed to its role in stress mitigation and cell division. The increase in seed yield in the present experiment might be attributed to foliar spraying of salicylic acid which improved translocation of photosynthates toward reproductive organs. This enhancement is visible in the increased seed yield of mustard. The combined application of hydrogel and salicylic acid further enhanced the yield characters and yield of mustard. Kumawat *et al.* (2021) also reported significant improvement in number of siliqua/plant, number of seeds/

Table 2 Effect of hydrogel and salicylic acid on yield attributes, yield and WUE of Indian mustard (Pooled data of three years)

Treatment	Siliquae/ plant	Seeds/ siliqua	Test weight (g)	Seed yield (kg/ha)	Stover yield (kg/ha)	WUE (kg/ha-mm)
T_1	171.5	10.1	3.38	1259	2753	6.37
T_2	188.7	11.5	3.86	1448	2967	7.47
T_3	193.6	11.8	4.08	1498	3141	8.23
T_4	184.8	11.4	3.84	1441	2694	6.73
T_5	189.6	11.6	3.93	1455	2743	6.77
T_6	208.6	13.1	4.17	1700	3568	7.87
T_7	211.4	13.4	4.24	1714	3605	7.90
T_8	216.8	13.9	4.34	1811	3822	8.43
T_9	223.0	14.1	4.42	1840	3847	8.53
SEm±	3.81	0.22	0.06	27.3	90.8	0.16
CD (*P*=0.05)	11.4	0.66	0.20	81.9	272.4	0.47

Treatment details are given under Materials and Methods.

siliqua and test weight of taramira due to the combined application of 5.0 kg hydrogel/ha and salicylic acid 100 ppm. These results also corroborate with the findings of Meena *et al.* (2020).

The combined data from three years of the study revealed that the application of 5.0 kg/ha of hydrogel along with 200 ppm of salicylic acid during the flowering and siliqua formation stages proved to be the most effective, exhibiting the highest water use efficiency (8.53 kg/ha-mm) for Indian mustard. This performance was statistically similar to the treatment involving 5.0 kg/ha of hydrogel in combination with 100 ppm of salicylic acid, which resulted in a water use efficiency of 8.43 kg/ha-mm. Notably, both of these treatment combinations significantly outperformed the other treatments applied (Table 2). The WUE of Indian mustard exhibited a notable increase of 33.9% due to the soil application of 5.0 kg/ha of hydrogel along with 200 ppm of salicylic acid compared to the control. Furthermore, the single applications of 5.0 kg/ha and 2.5 kg/ha of hydrogel, as well as salicylic acid at 200 ppm and 100 ppm, all demonstrated a significant enhancement in the water use efficiency of mustard when compared to the control. The enhanced water use by mustard crop could be attributed to the fact that hydrogel gradually released water, improved soil structure, promoted root growth and reduced irrigation frequency. These combined effects culminated in an overall increment in crop yield. Similar findings have also been reported by Rathore *et al.* (2020) in mustard. Bharat *et al.* (2019) also observed the higher seed yield and WUE of Indian mustard with application of hydrogel, further supporting the notion that the use of hydrogel can be a valuable and sustainable strategy for maximizing crop and water productivity.

Quality and economics: The experimental results consistently demonstrated that, over the course of all three years, the highest protein content (18.6%) and seed oil content (39.3%) were observed when the combination of 5.0 kg/ha of hydrogel and 200 ppm of salicylic acid was applied. This outcome was statistically equivalent to the treatments involving 5.0 kg/ha of hydrogel with 100 ppm of salicylic acid, 2.5 kg/ha of hydrogel with 200 ppm of salicylic acid, and 2.5 kg/ha of hydrogel with 100 ppm of salicylic acid. These treatments significantly exceeded the protein and oil content of the control (Table 3). Moreover, the individual application of hydrogel and salicylic acid at varying concentrations also showed improvements in protein and oil content of the seeds compared to the control treatment. In this study, the utilization of hydrogel, salicylic acid, and their combined application fostered a more favourable nutritional environment within both the soil and plant system. In this research, the utilization of hydrogel, salicylic acid, and their combined application created a more conducive nutritional environment for both the soil and plant system. Consequently, this led to a significant enhancement in the seed oil and protein content of the mustard crop. Similar results have been documented in a study conducted by Meena *et al*. (2020) on Indian mustard.

Table 3 Effect of hydrogel and salicylic acid on quality and economics of Indian mustard (Pooled data of three years)

Treatment	Protein content (%)	Oil content (%)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C ratio
T_1	17.1	37.39	54622	38134	2.30
T_2	17.7	38.10	62358	42710	2.19
T_3	17.8	38.20	64421	41346	1.81
T_4	17.5	38.17	62023	44535	2.55
T_5	17.8	38.33	62833	44345	2.40
T_6	18.0	38.57	71216	50301	2.44
T_7	18.2	38.67	72024	50276	2.35
T_8	18.5	38.93	76073	51331	2.09
T_9	18.6	39.13	77418	51710	2.03
SEm±	0.30	0.49	1885	1052	0.06
CD (*P*=0.05)	0.88	1.47	5652	3153	0.17

Treatment details are given under Materials and Methods.

When providing recommendations to farmers, the economic viability of treatments holds the highest importance. After conducting a comparative economic analysis of the various treatments, it was evident that the greatest gross returns (₹77,418/ha) and net returns (₹51,710/ha) were obtained through the application of 5.0 kg/ha of hydrogel combined with 200 ppm of salicylic acid during the flowering and siliqua formation stages. Closely following this, the treatment involving 5.0 kg/ha of hydrogel with 100 ppm of salicylic acid yielded gross returns of ₹76,073/ha and net returns of ₹51,331/ha, while the treatment with 2.5 kg/ha of hydrogel and 100 ppm of salicylic acid produced gross returns of ₹72,024/ha and net returns of ₹50,276/ha. These three treatments increased net returns by ₹13,576, ₹13,197 and ₹12,142/ha over the control, respectively. Furthermore, the application of hydrogel at rates of 2.5 kg/ha and 5.0 kg/ha, as well as salicylic acid at concentrations of 100 ppm and 200 ppm during the flowering and siliqua formation stages, resulted in increased gross returns and net returns compared to the control. However, the maximum benefit-cost (B:C) ratio (2.55) was observed with the foliar spray of salicylic acid at 100 ppm during the flowering and siliqua formation stages. This higher B:C ratio can be attributed to the lower cost associated with this treatment. The primary reason for the higher net returns achieved with the combined application of hydrogel and salicylic acid, as compared to other treatments, is likely due to the increased productivity of the crop. Additionally, the maximized water use efficiency, reduction in input costs, and improved nutrient availability contributed to economic gains. The correlation between increased yield and improved economic returns is in line with findings reported by Rehman *et al*. (2011) and Meena *et al.* (2020).

The results from a comprehensive three-year study lead to a conclusive recommendation for Indian mustard in semi-arid regions of Rajasthan. The optimal approach involves the application of hydrogel at rates of 5.0 kg/ha or 2.5 kg/ha, coupled with salicylic acid at either 200 ppm or 100 ppm during the flowering and siliqua formation stages for higher productivity, net returns and water use efficiency of Indian mustard. The implications of these results are significant for sustainable agricultural practices in water-limited environments, providing valuable insights for optimizing mustard cultivation. By leveraging hydrogel and salicylic acid at specific stages of crop growth, farmers in semi-arid and arid regions of Rajasthan can maximize their mustard productivity despite challenging climatic conditions.

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