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Effect of superabsorbent polymer and plant bio-regulators on growth, yield and water productivity of Indian mustard (*Brassica juncea* L.) under different soil moisture regimes

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Abstract

A field experiment was conducted during 2018-19 to evaluate the field efficacy of superabsorbent polymer (SAP: Pusa hydrogel) and plant bio-regulators (PBR's) on growth, yield attributes, yields and water productivity of Indian mustard (*Brassica juncea* L.). Different PBR's like salicylic acid (SA, 100 ppm), thiourea (TU, 0.1%) and potassium nitrate (PN, 1.5%) along with SAP (2.5 kg/ha) were compared with control under moisture stress and normal moisture regimes in a factorial randomized complete block design with three replications. Crop under normal moisture regimes obviously resulted the maximum values of growth, development and yield parameters than the moisture stress regime. The combined application of SAP+PBR's, especially SAP+SA followed by SAP+TU further improved these growth and yield parameters under both the moisture regimes, but greater response was observed under moisture stress regime. The negative effect of moisture stress on growth and yield parameters led to significant decrease in seed, stover and biological yields by on an average 11.3, 6.7 and 8.0 %, respectively over the normal moisture regime. Further, seed yield penalty due to moisture stress was recorded the maximum under the control (17.7-20.4 %) followed by SAP (14.9 %) and least under the SAP+PBR's applied treatments (4.2-6.4 %). This signifies the beneficial role of SAP and PBRs in mitigating the moisture stress and reducing the yield losses under deficit moisture conditions. Among different moisture stress mitigation options, the highest seed yield (2.63 t/ha) and biological yield (9.47 t/ha) were recorded with SAP+SA which was remained on par with SAP+TU and SAP+PN but significantly higher by 8.7-24.6 % and 4.8-17.6 %, respectively over the rest of the treatments. The water productivity was recorded significantly higher (~ 9.6 %) under moisture stress than the normal moisture regime. Further, SAP+SA resulted the maximum water productivity under both moisture stress (1.83 kg/m^3) and normal moisture (1.56 kg/m^3) regimes, which was also found to improve water productivity significantly by 15.8-41.9 % over the SAP and control treatments under moisture stress regime while by 17.2 % over the control under normal moisture regime. Thus, the use of PBR's along with SAP can be recommended to maximize the yield and water productivity levels of Indian mustard, in addition to save the irrigation water under rainfed/limited water availability conditions.

Keywords: *Indian mustard, moisture stress, superabsorbent polymer, plant bio-regulators, water productivity, yield*

Introduction

India is the fourth largest vegetable oil economy in the world next to USA, China and Brazil. Oilseeds are the second largest contributor in Indian agricultural economy after the cereals. Being second largest grower (21.1 %) after Canada, and third largest producer (12.6 %) after Canada and China, India plays a key role in global rapeseed–mustard industry (FAOSTAT, 2022). However, the net domestic availability of edible oil has not been found sufficient to meet out the demand of growing population of India. Therefore, India imports around 50 to 60 % of total consumption of edible oil every year with the cost of huge foreign exchange, and it was 13.45 mt of the worth Rs. 82,123 crores during 2020-21 (Anonymous, 2021). As per the estimates, India will require 29.0-34.0 mt of vegetable oils and 82-102 mt of oilseeds by 2030 to meet the demand of rising population (Chauhan *et al.*, 2020). Rapeseed-mustard is an important group of oilseed crops in India. During 2020-21, rapeseed–mustard occupies around 23.3 % area (6.69 mha) and 26.8 % (10.11 mt) production of total oilseeds in the country and contributes around 24.4 % of total vegetable oil production through nine oilseed crops, thus it is playing a pivotal role in meeting the edible oil requirements of the country (Anonymous, 2021). However, the productivity levels of the rapeseed-mustard group of crops in India are about 2/3[rd] of the world level owing to large scale cultivation under rainfed conditions where crop often encounter biotic and abiotic stresses, and resources crunch (Jat *et al.,* 2019; Jat *et al.,* 2021). Indian mustard (*B. juncea* L.) is a popularly grown crop in India, accounting for more than 90 % of rapeseed-mustard cultivated area with the maximum area in Rajasthan. Rajasthan is having the limited irrigation resources and drought prone too, hence crop frequently faces deficit moisture stress during critical crop growth periods. Moisture stress during growing season in rapeseed-mustard could reduce the production by 17 to 94 % (Chauhan *et al.,* 2011). Further, moisture stress at post flowering stages of the crop has led to a drastic decline in growth and yields of Indian mustard (Choudhary *et al.,* 2021; Langadi *et al.,* 2021). Further, the water available for irrigation is mostly applied at 30-40 days after sowing which fails to meet the water requirement of crop at later critical crop growth stages (Rathore *et al.,* 2019). Thus, there is need to improve the drought tolerance ability of the crop, and to maintain the moisture supply in the root zone throughout the crop growing period to meet the water requirements during the reproductive stages for achieving the higher yields and water productivity.

The plant drought stress tolerance can be improved with an exogenous use of stress alleviating chemicals. Many plant bio-regulators (PBR's) and plant hormones have been recently tried to impart stress tolerance to crop under water deficit conditions (Shah *et al.,* 2021; Wakchaure *et al.,* 2016a; Wakchaure *et al.,* 2016b; Srivastava *et al.,* 2016). Salicylic acid (SA, 2-hydroxybenzoic acid) is a plant hormone which plays a pivotal role in regulating numerous plant morpho-physiological and biochemical processes including seedling growth, stomatal regulation, photosynthetic rate, leaf senescence and flowering, enzyme activities in crops including edible oilseed crop plants (Pluharova *et al.,* 2019; Shaki *et al.,* 2020). Alam *et al.* (2013) reported that SA alleviated short-term drought stress in mustard seedlings via upregulating the antioxidant system. Thiourea (TU) containing one SH group (sulfhydryl compound) helps to improve phloem translocation of photosynthate in crop plants and thereby, induces drought and salinity tolerance in cereals, pulses, oilseeds and spices (Bhunia *et al.,* 2015). Potassium nitrate (PN) containing the potassium (K) which is a key element for crops growth, productivities and an indication of drought stress (Demidchik *et al.,* 2014). Further, the use of superabsorbent polymer (SAP) like 'Pusa Hydrogel' have been advocated by many researchers for soil moisture conservation and thereby moisture stress mitigation in several crops including the mustard (Choudhary *et al.,* 2021; Rathore *et al.,* 2019; Bana *et al*., 2018;). Therefore, the present study was conducted with the objective to determine the field efficacy of PBR's and hydrogel for improving the water productivity of Indian mustard under different soil moisture regimes.

Materials and Methods

A field experiment was conducted during *rabi* season of 2018-19 at the research farm of ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur (27°12'8.9" N latitude and 77°27'18.8" E longitude at an altitude of 178.4 m above MSL). The climate of the experimental area is dry with hot summer, a cold winter and a short monsoon. The average rainfall of the locality is around 650 mm of which 85 % is contributed by south-west monsoon during July to August. During the crop season of 2018-19, total rainfall received was 37.4 mm. The daily values of the maximum and minimum temperature, maximum and minimum relative humidity, bright sunshine hours and wind velocity during the crop growing period were ranged between 15-34.8 °C, 0.4-21.8°C, 70.5-97.3 %, 45.3-89.4 %, 0-10 hours/day and 0-7.6 km/hr, respectively. Before start of the experiment, surface soil (0-15 cm) samples were collected and analyzed to determine the soil physical and chemical properties. The experimental soil at site was clay loam in texture and it had 0.41 % organic carbon, 225.1 kg/ha $KMnO_4$ oxidizable nitrogen, 20.1 kg/ha 0.5 N $NaHCO_3$ extractable phosphorus, 172.4 kg/ha 1.0 N NH_4OAc exchangeable potassium, 8.2 pH and 0.72 dS/m electrical conductivity. The twelve treatment combinations consisting two moisture regimes (normal moisture and moisture stress) and six treatment of moisture stress mitigation options which included three plant bio-regulators [(PBR's; salicylic acid, SA (100 ppm); thiourea, TU (0.1%); potassium nitrate, PN (1.5%)] along with a superabsorbent polymer-pusa hydrogel (SAP, 2.5 kg/ha), SAP alone (2.5 kg/ha), water spray as control and an absolute control (without PBR, SAP and water). Treatments were accommodated in a factorial randomized block design and with three replications of each treatment. SAP was drilled in the root zone at sowing time of the crop as per the treatments. The PBR's were sprayed at flower initiation and siliqua formation stages of the mustard. One irrigation (34 days after sowing, DAS) under moisture stress and two irrigations (34 and 70 DAS) under normal moisture regimes were applied to the mustard. Thereby moisture stress regime was created through with-holding the 2^{nd} irrigation. The sowing of the crop (var. DRMRIJ 31) was done on 18 October 2018 with a seed drill using 4 kg seeds/ha. The interculture operations including the gap filling and thinning were performed and a planting geometry of 45 cm × 10-15 cm was kept to maintain the optimum plant population. The recommended dose of fertilizers viz., 80:40:40:40:5:1 kg/ha of

$N:P_2O_5:K_2O:S:Zn:B$ were uniformly applied to all the treatments through urea, single super phosphate, muriate of potash, zinc sulphate and borax fertilizers. 50 % dose of N and 100 % dose of recommended remaining nutrients were applied as basal at the time of sowing, while remaining another half dose of N was top dressed after first irrigation. One hand weeding with a hand hoe was done during 25-30 DAS to remove the weeds from the experimental plots. Other recommended crop management practices were followed to harvest a good crop. The observations on different growth and yield parameters including plant height; main shoot length; number of primary and secondary branches; number of siliquae, siliqua length and seeds per siliqua associated with main shoot, primary and secondary branches were recorded by following the standard methods. Plant height was measured at 45 DAS and at maturity, while observations on different yield parameters were recorded at the maturity of the crop. The crop was harvested on 9th March 2019 when 75 % siliquae turned down yellowish brown. A 4.5 m × 6.0 m net plot area was selected for harvest of the crop after removing the crop from border of each plot. After proper sun drying in the field, total produce harvested from each plot was first weighted for the total biological yield and then threshed and cleaned. The seeds obtained were weighed and then expressed the seed yield in t/ha. Stover yield was computed by deducting the seed yield from the total biological yield of respective plots. Water productivity (kg/m^3) of seed produced was calculated as the ratio of seed yield to crop water use by following the procedure as described by Ali *et al.* (2007). The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique for a factorial randomized block design using SAS package (*ver.* 9.3). The results have been presented at 5 % level of significance (P=0.05).

Results and Discussion

Growth parameters

The effect of different soil moisture regimes and moisture stress mitigation options on different growth parameters of Indian mustard *viz.*, plant height, number of primary branches, number of secondary branches and main shoot length was found significant (Table 1). Though, at 45 DAS, plant height did not differ significantly, but it was varied significantly at maturity due to different treatments (Table 1). At maturity, plants were 4.8 % taller under normal moisture regime than the moisture stress condition. Among different moisture stress mitigation options, the tallest plants (218.1 cm) were recorded with application of SAP+TU which was remained on par with other treatments of SAP and PBRs, but significantly higher than the control and water spray treatments. The non-significant variation in plant height under different treatments at 45 DAS was due to uniform supply of soil moisture through application of an irrigation at 35 DAS. But, deficit moisture supply during the post flowering period might have exposed the crop to relatively more water stress which led to decline in plant height at maturity under the moisture stress regime. The numbers of primary and secondary branches were significantly reduced by 7.0 and 22.4 %, respectively due to moisture

Table 1: Effect of soil moisture regimes and moisture stress mitigation options on growth parameters of Indian mustard

Treatment	Plant height (cm)		Number of branches		Main shoot
	45 DAS	At maturity	Primary	Secondary	length (cm)
A. Soil moisture regimes					
Normal moisture	60.0	217.0	8.6	16.5	81.7
Moisture stress	58.4	207.1	8.0	12.8	70.7
SEm±	1.0	2.0	0.1	0.4	1.2
LSD (*P* = 0.05)	NS	6.0	0.4	1.1	3.5
B. Moisture stress mitigation options					
SAP	57.8	213.1	8.6	14.5	75.5
SAP+TU	58.4	218.1	8.9	15.6	79.0
SAP+PN	61.3	216.0	8.8	15.3	79.1
SAP+SA	60.2	215.7	9.0	16.7	81.0
Water	60.0	205.0	7.2	13.0	71.8
Control	57.3	204.3	7.2	12.8	70.8
SEm±	1.78	3.5	0.2	0.6	2.1
LSD (*P* = 0.05)	NS	10.3	0.6	1.9	6.1
A × B					
SEm ±	2.48	5.0	0.3	0.9	2.9
LSD (*P* = 0.05)	NS	NS	NS	NS	NS

stress as compared to normal moisture condition (Table 1). Among different moisture stress mitigation options, the maximum numbers of primary and secondary branches were recorded under SAP+SA which was significantly higher than the control and water spray treatments in case of primary branches, and it was (SAP+SA) recorded significantly higher than SAP alone, control and water spray treatments in case of secondary branches. This might be due to the use of SAP and PBRs which favored the development of branches by way of maintaining a better moisture regime in the soil. Similar results have also been reported by Singh *et al.* (2018). Similarly, the main shoot length (MSL) was significantly reduced 13.5 % under moisture stress as compared to the normal moisture condition (Table 1). Among different moisture stress mitigation options, the maximum MSL (81.0 cm) was recorded with SAP+SA which was found on par with other SAP and PBR treatments but significantly higher (12.8-14.4%) over the control and water spray treatments. Hayat *et al.* (2009) reported that three foliar sprays of 10^{-5} M SA on 7-day-old seedlings of mustard simultaneously improved its root length by 13 %, shoot length by 14.7 %, plant fresh mass by 14.0 % and plant dry mass by 35.5 % compared with the control.

Yield attributes

The number of siliquae on primary branch did not differ significantly due to different soil moisture regimes. Though, numbers of siliquae associated with secondary branch and main shoot were decreased significantly by 7.4 and 11.6 %, respectively under the moisture stress as compared to the normal moisture condition (Table 2). Among different moisture stress mitigation options, the maximum number of siliquae per primary branch (41.0) was recorded with SAP+SA which was found on par with SAP+TU and SAP+PN treatments but significantly higher than the SAP, water and control treatments. Similar trend was observed in case of number of siliquae per secondary branch and number of siliquae on main shoot. SAP+SA increased the number of siliquae over the SAP and control treatments by 19.2 and 36.7 % on the primary branch, by 17.9 and 43.1 % on secondary branch and by 11.9 and 28.6 % on main shoot, respectively. The maximum length of the siliqua on primary branch, secondary branch and main shoot was recorded under normal moisture condition, while these were significantly reduced by 5.9, 8.3 and 5.7 %, respectively due to moisture stress (Table 2). Among different moisture stress mitigation options, the maximum length of the siliqua on primary branch, secondary branch and main shoot was registered under SAP+SA closely followed by SAP+TU and SAP+PN treatments, which was also recoded significantly higher over the water and control treatments. Thus, application of SAP+SA increased the siliqua length by 17.0-19.0 % over the control. The number of seeds per siliqua associated with primary branch and main shoots were significantly decreased by 8.8 and 9.9 %, respectively due to moisture stress over the normal moisture condition. Number of seeds per siliqua associated with secondary branch was also reduced non-significantly under the moisture stress than the normal moisture condition (Table 2). The number of seed per siliqua also influenced significantly due to different moisture stress mitigation treatments. However, the effect of different moisture stress mitigation options on seeds per siliqua of the primary branch was found non-significant. The maximum number of seeds per siliqua (14.9) of the secondary branch was recorded under SA+SA which was found significantly higher than the water and control treatments, but it remained statistically on par with other SAP and PBR treatments. Further, SAP+SA being on par with other SAP and PBR treatments also resulted the maximum number of seeds per siliqua (18.0) of main shoot which was also significantly higher than the water and control treatments.

The higher values of yield attributes under normal moisture regime over the moisture stress regime, and SAP+PBRs (particularly with SA) over the control treatments might be due to improved growth and development of the plants. Singh *et al.* (2018) reported that application of irrigation and SAP ensured a higher availability of nutrients which resulted in a greater number of branches and culminated in a better sink development leading to more siliquae per plant. The optimum soil moisture maintained during the crop growth stages with SAP application signiûcantly improves the number of branches per plant, number of siliquae and seeds per siliqua of Indian mustard (Choudhary *et al.*, 2021; Rathore *et al.*, 2019). Further, PBRs also mediates the response of plants and provide the drought tolerance under moisture stress conditions (Shah *et al.*, 2021; Pluharova *et al.*, 2019; Demidchik *et al.*, 2014). Fariduddin *et al.* (2003) reported that spray treatment of 10^{-5} M SA on mustard at post flowering stage enhanced its pod number by 161.2 %, seed number by 10.8 % and seed yield by 7.0 % than the water-treated control.

Seed, stover and biological yields

The seed, stover and biological yields of the Indian mustard were influenced significantly under different soil moisture regimes as well as under different moisture stress mitigation options (Table 3). The optimal supply of irrigation water resulted in the maximum seed yield (2.56 t/ha) under normal moisture condition, which was 12.8 % higher over the moisture stress regime. The seed yield penalty due to moisture stress was recorded the maximum

Table 2: Effect of soil moisture regimes and moisture stress mitigation options on yield attributes of Indian mustard

Treatment	Number of siliquae			Siliqua length (cm)			Seeds per siliqua		
	Primary branch	Secondary branch	Main shoot	Primary branch	Secondary branch	Main shoot	Primary branch	Secondary branch	Main shoot
A. Soil moisture regimes									
Normal moisture	36.6	35.0	64.4	5.1	4.8	5.3	15.9	14.2	17.2
Moisture stress	34.0	32.4	56.9	4.8	4.4	5.0	14.5	13.4	15.5
SEm±	1.1	0.9	0.8	0.1	0.1	0.1	0.4	0.3	0.4
LSD (P = 0.05)	NS	2.5	2.3	0.3	0.3	0.3	1.1	NS	1.1
B. Moisture stress mitigation options									
SAP	34.4	33.5	60.3	4.8	4.6	5.1	15.3	13.8	16.3
SAP+TU	38.7	38.0	64.6	5.1	4.9	5.3	15.8	14.6	17.8
SAP+PN	37.5	36.0	65.3	5.1	4.8	5.4	15.5	14.5	17.0
SAP+SA	41.0	39.5	67.5	5.3	5.0	5.5	16.3	14.9	18.0
Water	30.3	27.5	53.8	4.7	4.3	4.7	14.3	12.6	14.7
Control	30.0	27.6	52.5	4.5	4.2	4.7	13.9	12.5	14.4
SEm±	1.9	1.5	1.3	0.2	0.2	0.2	0.7	0.6	0.6
LSD (P = 0.05)	5.6	4.4	3.9	0.5	0.5	0.5	NS	1.7	1.9
A × B									
SEm±	2.7	2.1	1.9	0.2	0.2	0.2	0.9	0.8	0.9
LSD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

under the water spray and control treatments (17.7-20.4 %) followed by SAP (14.9 %) and least under the SAP+PBRs (4.2-6.4 %). This signifies the beneficial role of SAP and PBRs in mitigating the moisture stress and reducing the yield losses under deficit moisture conditions. Similarly, the maximum values of stover yield (6.71 t/ha) and biological yield (9.27 t/ha) were also recoded under normal moisture regime, while these yield parameters were decreased under the moisture stress regimes over the normal moisture regime by on an average 6.7 and 8.0 %, respectively (Table 3). The higher seed, stover and biological yields of the Indian mustard under normal moisture regime over the moisture stress regime was due to improved growth and yield parameters of the crop under the former soil moisture regime. Choudhary *et al.* (2021) reported the 13.2-19.5 % and 8.1-11.5 % reduction in seed and stover yields, respectively under moisture stress condition over the normal moisture condition. Singh *et al.* (2018) reported that application of irrigation increased the seed yield significantly over no irrigation. Among different moisture stress mitigation options, the maximum mean seed yield was recorded with SAP+SA (2.63 t/ha), being on par with SAP+TU and SAP+PN but significantly higher by 8.7, 20.1 and 24.6 % over the SAP, water and control treatments, respectively (Table 3). Averaged across different soil moisture regimes, the maximum stover yield (6.84 t/ha) was registered with SAP+SA which remained on par with SAP+TU, SAP+PN and SAP but significantly higher (11.6-15.2 %) than the water and control treatments. Similarly, the maximum mean biological yield was recorded with SAP+SA (9.47 t/ha), being on par with SAP+TU and SAP+PN but significantly higher by 4.8, 14.0 and 17.6 % over the SAP, water and control treatments, respectively (Table 3). Furthermore, the SAP and PBRs triggered the greater response under moisture stress regime as compared to the normal moisture regime. Under the moisture stress regime, the seed, stover and biological yields were increased by 19.3-37.4, 13.3-18.7 and 14.8-23.5 %, respectively with the use of SAP and SAP+PBRs over the control, but under the normal moisture regime, corresponding figure were 11.5-14.5, 9.6-11.8 and 10.0-12.6 %. Thus, use of SAP+PBRs was found more beneficial under moisture stress regime than the normal moisture regime.

SAP mitigates the negative effects of deficit moisture stress through enhanced supply of water to the stressed plants. Choudhary *et al.* (2021) reported that application of pusa hydrogel @ 2.5 and 5.0 kg/ha increased the seed yield of Indian mustard by 18.3 % and 23.3 %, respectively under normal moisture, while under moisture stress condition it increased by 14.9 and 28.6 %, respectively over the control. Further, PBRs play an important role in the growth and development of the plant for important physiological roles such as increasing the plant's response to stress conditions (Shah *et al.*, 2021; Pluharova *et al.*, 2019; Demidchik *et al.*, 2014). SA contributes to drought tolerance through increasing leaf pigments, carboxylase activity of rubisco, preventing ethylene synthesis and scavenging reactive oxygen species (ROS) by enhancing antioxidant enzymes activities. Meena *et al.* (2020) reported that the foliar spray of 200 ppm SA substantially increased the yield attributes, seed yield, oil content and oil yield of mustard. Wakchaure *et al.* (2016a) also reported a significant increase in wheat grain yield with the exogenous application of TU, SA and KNO_3 over the control under water deficit conditions.

Water productivity

The water productivity was significantly influenced due to different soil moisture regimes as well as different moisture stress mitigation options (Table 3). Averaged across different moisture stress mitigation options, the water productivity was recorded 9.6 % higher under the moisture stress regime over the normal moisture regime. As the fact that under deficit water conditions, the most of the irrigation water applied remains in the root zone and also lesser quantity get lost through evapotranspiration are might be reason for the higher water productivity under moisture stress regime (Fereres and Soriano, 2007). Choudhary *et al.* (2021) also reported the higher water productivity of Indian mustard under moisture stress condition over the normal moisture. Averaged across different soil moisture regimes, the maximum water productivity (1.69 kg/m^3) was recorded with SAP+SA which remained on par with SAP+TU and SAP+PN but significantly higher by 9.7, 26.1 and 29.0 % over the SAP, water and control treatments, respectively (Table 3). Further, the interaction effect of different soil moisture regimes and moisture stress mitigation options on the water productivity was found significant (Table 3). Under moisture stress regime, the water productivity was significantly increased with SAP and SAP+PBR treatments over the water and control treatments. Whereas, under normal moisture regime, the water productivity did not influence significantly due to different moisture stress mitigation options, except the SAP+SA. Nevertheless, the maximum water productivity under both the moisture regimes was recorded with the use of SAP+SA which was also recorded significantly higher by 17.3 and 41.9 % under normal moisture and moisture stress regimes over their respective control treatments. In general, the water productivity improves with decrease in supply of soil moisture. But interestingly, both water spray and control treatments resulted the lower values of water productivity under moisture stress regime

Table 3: Effect of soil moisture regimes and moisture stress mitigation options on yield and water productivity of Indian mustard

Treatment	Soil moisture regimesMoisture stress mitigation options						Mean
	SAP	SAP+TU	SAP+PN	SAP+SA	Water	Control	
Seed yield (t/ha)							
Normal moisture	2.62	2.64	2.64	2.69	2.41	2.35	2.56
Moisture stress	2.23	2.53	2.47	2.57	1.96	1.87	2.27
Mean	2.42	2.58	2.55	2.63	2.19	2.11	
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm±		0.04			0.07		0.10
LSD (P = 0.05)		0.11			0.19		0.32
Stover yield (t/ha)							
Normal moisture	6.85	7.02	6.88	6.99	6.27	6.25	6.71
Moisture stress	6.38	6.49	6.41	6.68	5.98	5.63	6.26
Mean	6.61	6.75	6.65	6.84	6.13	5.94	
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm±		0.09			0.15		0.22
LSD (P = 0.05)		0.26			0.45		NS
Biological yield (t/ha)							
Normal moisture	9.46	9.66	9.52	9.68	8.68	8.60	9.27
Moisture stress	8.61	9.01	8.88	9.26	7.94	7.50	8.53
Mean	9.04	9.34	9.20	9.47	8.31	8.05	
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm±		0.07			0.13		0.18
LSD (P = 0.05)		0.22			0.38		NS
Water productivity (kg/m^3)							
Normal moisture	1.49	1.51	1.52	1.56	1.35	1.33	1.46
Moisture stress	1.58	1.79	1.76	1.83	1.34	1.29	1.60
Mean	1.54	1.65	1.64	1.69	1.34	1.31	
		A. Soil moisture regimes			B. Moisture stress mitigation options		A × B
SEm±		0.02			0.04		0.07
LSD (P = 0.05)		0.07			0.12		0.21

than the normal moisture regime, though other treatments resulted the higher values of water productivity. This signifies the beneficial role of SAP and PBRs in alleviating the adverse effect of moisture stress and achieving higher water productivity levels, particularly under moisture stress conditions. Furthermore, Choudhary *et al.* (2020) reported that water productivity increased with N and irrigation levels up to a certain level but then decreased. They further revealed that even higher WP with lesser quantity of water could be achieved with judicious management of N by keeping water availability under consideration. The higher water productivity under moisture stress regime and SAP+PRRs applied treatments was also due to comparatively lesser water use and higher yields performance of the crop. Choudhary *et al.* (2021) reported the higher seed yield and water productivity of Indian mustard with pusa hydrogel (2.5-5.0 kg/ha) over the without hydrogel treatments. Wakchaure *et al.* (2016a) also reported the higher water productivity values in wheat with the exogenous application of PBRs (TU, SA and PN) over the without PBRs under various irrigation levels (0.1 to 1.0 IW:CPE ratio).

Conclusion

A post flowering drought stress was found unfavorable for Indian mustard and caused a yield penalty up to 20.4 % with significant reduction in growth and yield parameters. Superabsorbent polymer (pusa hydrogel) and PBR's like salicylic acid, thiourea and potassium nitrate were identified to aid in alleviation of moisture stress. These not only increased the seed yield (13.8-37.4 %) but also improved the water productivity (17.9-41.9 %) and saved one irrigation water under the moisture stress regime. The maximum gain in yields and water productivity was observed with combined application of SAP+SA followed by SAP+TU and SAP+PN. The combined use of SAP and PBRs mitigated the post flowering drought stress; thus, these can be recommended for use to enhance the yield and water productivity of the Indian mustard.

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