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Dry Matter Partitioning and Productivity of Wheat (*Triticum aestivum* L.) as Influenced by Sowing Thermal Regimes and Bio-regulators

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Authors' contributions

This work was carried out in collaboration among all authors. Author OPS designed the study. Author HL performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HPV and MC managed the analyses of the study. Author RB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was carried out during the *rabi* seasons of 2016-17 and 2017-18 at Agronomy Farm, S.K.N. Agriculture University, Jobner, Jaipur, Rajasthan, to evaluate the effect of sowing at different thermal regimes and foliar sprays of bio-regulators on growth and yield of wheat. The treatments comprised three sowings (22ºC, 20ºC and 18ºC) and eight bio-regulators (control, water spray, SA @ 100 ppm, SA @ 200 ppm, TSA @ 100 ppm, TSA @ 200 ppm, TGA @ 100 ppm and TGA @ 200 ppm). The experiment was conducted in split plot design with 4 replications. Wheat sown at 20ºC showed superior performance in respect of dry-matter partitioning and yield parameters, i.e. grain, straw biological and yields as compared to sowing at 22ºC and 18ºC. Amongst the bio-regulators options, an application of SA @ 200 ppm resulted in better performance, being comparable with those of TSA @ 200 ppm and TGA @ 200 ppm. Crop sown at 20ºC along with SA @ 200 ppm was found to be a better option for maximum dry matter accumulation and productivity of wheat under heat stress.

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Keywords: Bio-regulators; dry matter partitioning; sowing temperature; wheat; yield.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the significant cereal in India, by providing more than 50% of the calories to the people contributing considerably to the national food security [1]. India is the 2nd largest producer of wheat after China in the world from the last several years [2]. Wheat is grown in India on 33.61 Mha and produces of 106.21mt with national average yield of 3160 kg/ha during 2019-20 [3]. In Rajasthan, the production reached the level 12.19 m t with productivity of 3676 kg/ha and acreage 3.31 m ha [4]. Being a staple food, it is used to prepare cakes, cookies, biscuits, bread and noodles etc. and some remedial magnitude also [5]. In India, wheat production is constrained by salinity, drought, heat stress and climate change [6].

The anthropogenic emissions of greenhouse gases cause globally and in India climate change, an increasing trend has been observed in air temperatures [7,8,9]. It is well recognized that the yield losses increase with rising temperature [10,11,12]. The environmental factors including light, temperature, rainfall and relative humidity are strongly determined the crop growth and yield [13]. Variation among the weather conditions, selection of suitable sowing temperature is vital option to acquire high productivity [14]. At optimum temperature, early sowing enhances the wheat growth and yield, while delay in crop sowing cause reduction in yield due to temperature stress after anthesis reducing the kernel weight [15,16]. Sowing at optimum time could also enhance seed germination, dry matter accumulation and yield [17].

The well-known group of chemicals such as salicylic, thio-salicylic and TGA are significantly known as bio-regulators which are responsible towards biotic and abiotic stresses in plants [18]. For imparting stress tolerance to crops, application of these hormones has been recognized as a novel bio-regulator technology [7,19,20]. It also plays diverse physiological roles in plants including plant growth, nutrient uptake, flower induction, thermo genesis, and enzyme activities [21,22]. Hence, it is imperative to change the micro climate for better crop growth and yield of wheat [23]. The present study is an effort to evaluate the effect of sowing at different thermal environments and foliar spray of bio-regulators on dry matter partitioning and productivity of wheat under semi-arid eastern plain zone of Rajasthan.

2. MATERIALS AND METHODS

2.1 Experimental Site, Climate and Soil

An experiment was laid out during the *rabi* seasons of 2016-17 and 2017-18 at the Agronomy Farm of S.K.N. College of Agriculture, Jobner situated at latitude of 26^0 05’ North, longitude of 75^0 28’ East and at an altitude of 427 metres above mean sea level. The maximum temperature noted ranged from 34.8 ^{0}C to 20.4 ^{0}C during 2016-17 and 34.0 to 23.6 ºC during 2017-18 and minimum temperature ranged from 02.8 to 15.1 ºC during 2016-17 and 01.4 to 13.5ºC during 2017-18 (Table 1). During the crop season 24.8 mm and 5.6 mm in both the years, respectively rainfall was received. The site was well-drained, loamy sand soil with pH value of 8.25 (1:2 soil water suspension) and poor in organic carbon (0.22%), low in available N (130.3 kg/ha), available P (15.2 kg/ha) and medium in available K (149 kg/ha).

2.2 Experimental Design and Treatments Details

The experiment was carried out in a split-plot design with four replications. The sowing at different thermal environments was subjected to main plots while foliar spray of bio-regulators in subplots. A combination of 24 treatments, consisting of three sowings, viz. D_1 (22ºC), D_2 (20ºC), D_3 (18ºC) and eight bio-regulators, viz. B_1, control; B_2, water spray; B_3, salicylic acid @ 100 ppm; B_4, salicylic acid @ 200 ppm; B_5, thiosalicylic acid @ 100 ppm; B_6, thiosalicylic acid @ 200 ppm; B_7, thioglycolic acid @ 100 ppm; and B_8, thioglycolic acid @ 200 ppm. Bio-regulators were applied at tillering and ear emergence stages of crop by using foot sprayer.

2.3 Experimental Material and Cultural Practices

Wheat cultivar ‘Raj-3765’ was used for this study purpose. The field was prepared with tractor-drawn plough followed by harrowing, dry weeds and stubbles were discarded. The manually sowing was done with the help of kudal at a row spacing of 22.5 cm by using 100 kg/ha seed rate. The crop was irrigated at different critical stages of crop growth, besides pre-sowing irrigation.

Recommended dose of fertilizer of nitrogen (120 kg/ha) and P_2O_5 (40 kg/ha) were applied through urea (46% N) and DAP (46% P_2O_5). Nitrogen 50% and full dose of phosphorus were applied at the time of sowing and remaining nitrogen was applied at crown root initiation stage with first irrigation.

2.4 Data Analysis

Biometrical observations and yield were recorded by following standard practices. Data were recorded on growth attributes, viz. dry-matter accumulation and indices, grain and straw yields. For the assessment of dry matter distribution per plant, total five plants were selected from sampling rows of each plot. Stem, leaves and ear head were separated, dried and weighted. Dry matter translocation (g/plant), dry matter translocation efficiency (%) and contribution of pre anthesis assimilates to grain (%) were calculated by using the following formulae:

$\text{Dry matter translocation (g/plant)}$ =Dry matter at grain filling (90 DAS) - (leaves + stem + ear husk) dry matter at maturity

Dry matter translocation efficiency (%) $=\frac{\text{Dry matter translocation}}{\text{Dry matter at grain filling}}\text{X } 100$

Contribution of pre anthesis assimilates to grain $=\frac{\text{Dry matter translocation}}{\text{Grain yield/plant}}\text{X } 100$

From net plot area, crop was harvested and bundled for proper sun drying. Harvested produce was weighted for grain, straw and biological yield. The observations recorded for various parameters were statistically analysed to observe the significant difference among the treatment. The significance of the difference among the treatments means was assessed by the LSD at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Effect of Sowing at Different Thermal Environments

Sowing at different thermal environment treatments significantly influenced the dry matter accumulation, dry matter translocation (DMT), dry matter translocation efficiency (DMTE), contribution of pre-anthesis assimilates to grain and yield in wheat crop. The significantly higher dry matter accumulation per plant by leaves, stem, ear and total DMA at 30 and 90 DAS was recorded under treatment D_2 (sowing at 20ºC) which being at par with D_1 in respect of ear DMA at 90 DAS, superseded over rest of the treatments at both the crop growth stages. The lowest dry matter accumulation was noted with D_3. Similarly, the treatment D_2 (sowing at 20ºC) recorded significantly higher dry matter translocation (DMT), dry matter translocation efficiency (DMTE) and contribution of pre-anthesis assimilates to grain in wheat crop which proved significantly superior to D_1 and D_3 treatments. It might be due to variation in temperature, humidity and photosynthetically active radiation (PAR) within the crop canopy [24]. It is the fact that 15th November sown crop received maximum length of growing period and favourable temperature for the dry matter accumulation which might have increased the photosynthetic activity of plants, resulting to higher dry matter accumulation and translocation [25,26].

The significantly higher grain, straw and biological yield of wheat were recorded under D_2 with the respective values of 3771, 4880 and 8651 kg/ha. The lowest grain, straw and biological yield was noted with D_3 (3437, 4533 and 7970 kg/ha). The crop sown at 20ºC might have got favourable environment which facilitated better cell division, cell elongation, growth, photosynthesis and higher dry matter accumulation resulting in higher yield in comparison to late sown crop [25].

3.2 Effect of Foliar Spray of Bio-Regulators

Dry matter accumulation at 90 DAS, dry matter translocation (DMT), dry matter translocation efficiency (DMTE), contribution of pre-anthesis assimilates to grain and yield of wheat were significantly influenced by foliar spray of bio-regulator treatments. While, dry matter accumulation by leaves, stem and total DMA per plant did not vary significantly due to bio-regulator treatments up to 30 DAS. Application of SA @ 200 ppm (B_4) recorded the maximum dry matter accumulation by leaves, stem, ear and total DMA per plant and being at par with B_8 (TGA @ 200 ppm) in respect of leaves, stem DMA at 90 DAS found significantly superior in comparison to other treatments. The lowest dry matter accumulation was noted with the treatment B_1. Treatment B_4 (SA @ 200 ppm) recorded the maximum DMT and DMTE and being at par with B_8 (TGA @ 200 ppm) proved significantly superior over rest of the treatments.

However, the significantly higher contribution of pre-anthesis assimilates to grain was observed under the treatment B_8 and remaining at par with treatment B_4 and B_6 (TSA @ 200 ppm), superseded over rest of the treatments. It is fairly conceivable that bio-regulators might have stimulating the photosynthetic carbon fixation mechanism and hence might have increased canopy photosynthesis efficiency as well as due to its positive impact on translocation of photosynthetic assimilates towards active sink [27,28].

The significantly higher values of grain, straw and biological yield (3874, 4998 and 8873 kg/ha) of wheat were recorded under the application of salicylic acid @ 200 ppm over rest of the treatments while it remained at par with thiosalicylic acid and thioglycolic acid @ 200 ppm. The significantly lowest grain, straw and biological yield were obtained under control with the corresponding values of 3230, 4254 and 8240 kg/ha. Significant improvement in dry matter accumulation seems to be due to vigorous vegetative growth of plants which ultimately resulted in more leaf area and increased photosynthesis, thereby higher yield [29,30,31].

3.3 Interaction Effect

Data showed that combined effect between sowing at different thermal environments and foliar spray of bio-regulators was found to be non-significant with regard to dry matter accumulation and indices, straw, biological and yield of wheat. While, interaction effect of sowing at different thermal environments and foliar spray of bio-regulator treatments on grain yield of wheat was found to be significant. The treatment combination, D_2B_4 (sowing at 20°C along with the application of SA @ 200 ppm) recorded the significantly higher grain yield (4078 kg/ha) over rest of the treatment combinations except D_2B_2, D_2B_6, D_2B_8, D_1B_4, D_1B_6 and D_1B_8. The lowest grain yield was recorded under D_3B_2 (3053 kg/ha). The enhanced crop growth in terms of grain yield due to optimum environment obtained by crop [30].

Table 1. Mean weekly weather parameters recorded for crop season (*rabi*, 2016-17 and 2017-18)

SMW* No.	Period	Temperature °C				Relative Humidity (%)	
		Maximum		Minimum			
		2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
44	Oct.29 to Nov.04	33.0	30.3	11.0	11.9	55	43
45	Nov.05 to Nov.11	32.0	31.9	08.6	11.2	49	45
46	Nov.12 to Nov.18	30.4	29.6	08.7	11.6	53	51
47	Nov.19 to Nov. 25	31.0	25.7	06.6	05.6	49	51
48	Nov. 26 to Dec. 02	30.5	28.8	08.6	05.9	53	51
49	Dec. 03 to Dec. 09	29.4	25.1	06.2	06.8	59	53
50	Dec. 10 to Dec. 16	28.1	24.5	09.4	07.2	59	57
51	Dec. 17 to Dec. 23	27.2	25.6	04.4	04.7	54	50
52	Dec. 24 to Dec. 31	27.3	25.7	06.1	03.6	61	55
1	Jan. 01 to Jan. 07	24.4	23.6	07.2	01.4	71	59
2	Jan. 08 to Jan. 14	20.4	24.4	02.8	02.2	63	53
3	Jan. 15 to Jan. 21	21.1	27.1	04.9	03.4	63	51
4	Jan. 22 to Jan. 28	23.2	24.8	10.5	04.3	72	51
5	Jan. 29 to Feb. 04	24.7	27.8	09.9	06.1	65	48
6	Feb. 05 to Feb. 11	24.4	25.0	07.8	05.7	55	48
7	Feb. 12 to Feb. 18	27.9	26.6	08.9	07.9	49	49
8	Feb. 19 to Mar. 25	29.9	31.8	09.1	11.1	45	49
9	Feb. 26 to Mar. 04	30.8	32.7	11.1	13.4	49	47
10	Mar. 05 to Mar. 11	29.3	32.2	10.9	11.6	53	40
11	Mar. 12 to Mar. 18	28.6	34.0	10.5	12.7	47	41
12	Mar.19 to Mar. 25	34.8	32.5	15.1	13.5	47	41

SMW - Standard meteorological week*

Table 2. Effect of sowing at different thermal environments and foliar spray of bio-regulators on dry matter accumulation at 30 DAS (on pooled basis)

Treatments	DMA (g/plant) at 30 DAS		
	Leaves	Stem	Total
Sowing at different thermal environments			
D_1: 22°C	0.321	0.220	0.541
D_2: 20°C	0.325	0.223	0.548
D_3: 18°C	0.317	0.215	0.532
SEm±	0.001	0.001	0.002
CD (P=0.05)	0.01	0.01	0.005
Foliar spray of bio-regulators			
B_1: Control	0.311	0.208	0.519
B_2: Water spray	0.316	0.214	0.530
B_3: SA @ 100 ppm	0.320	0.220	0.540
B_4: SA @ 200 ppm	0.333	0.229	0.562
B_5: TSA @ 100 ppm	0.322	0.222	0.544
B_6: TSA @ 200 ppm	0.319	0.220	0.539
B_7: TGA @ 100 ppm	0.320	0.217	0.537
B_8: TGA @ 200 ppm	0.325	0.226	0.551
SEm±	0.002	0.002	0.004
CD (P=0.05)	NS	NS	NS
Interaction (D x B)			
SEm±	0.004	0.004	0.006
CD (P=0.05)	NS	NS	NS

Table 3. Effect of sowing at different thermal environments and foliar spray of bio-regulators on dry matter accumulation at 90 DAS (on pooled basis)

Treatments	DMA (g/plant) at 90 DAS			
	Leaves	Stem	Ear	Total
Sowing at different thermal environments				
D_1: 22 °C	1.17	3.04	2.61	6.83
D_2: 20 °C	1.20	3.14	2.64	6.95
D_3: 18 °C	1.15	3.03	2.59	6.80
SEm±	0.00	0.01	0.01	0.01
CD (P=0.05)	0.01	0.03	0.03	0.02
Foliar spray of bio-regulators				
B_1: Control	1.07	2.78	2.20	6.05
B_2: Water spray	1.11	2.84	2.33	6.28
B_3: SA @ 100 ppm	1.18	3.14	2.66	6.98
B_4: SA @ 200 ppm	1.26	3.30	3.02	7.58
B_5: TSA @ 100 ppm	1.14	2.95	2.44	6.54
B_6: TSA @ 200 ppm	1.19	3.23	2.81	7.23
B_7: TGA @ 100 ppm	1.19	3.06	2.53	6.78
B_8: TGA @ 200 ppm	1.25	3.27	2.92	7.44
SEm±	0.01	0.01	0.01	0.01
CD (P=0.05)	0.03	0.03	0.03	0.04
Interaction (D x B)				
SEm±	0.01	0.01	0.02	0.03
CD (P=0.05)	NS	NS	NS	NS

Table 4. Effect of sowing at different thermal environments and foliar spray of bio- regulators on dry matter translocation, dry matter translocation efficiency and contribution of pre anthesis assimilates to grain

Treatments	Dry matter translocation (g/plant)	Dry matter translocation efficiency (%)	Contribution of pre-anthesis assimilates to grain (%)
Sowing at different thermal environments			
D_1: 22 ^oC	0.94	13.53	33.99
D_2: 20 ^oC	1.04	14.83	36.55
D_3: 18 ^oC	0.86	13.38	33.03
SEm±	0.03	0.09	0.97
CD (P=0.05)	0.04	0.27	2.55
Foliar spray of bio-regulators			
B_1: Control	0.65	11.23	24.86
B_2: Water spray	0.71	11.81	27.36
B_3: SA @ 100 ppm	1.01	14.37	36.81
B_4: SA @ 200 ppm	1.21	15.32	41.44
B_5: TSA @ 100 ppm	0.88	13.28	32.89
B_6: TSA @ 200 ppm	1.08	15.45	38.33
B_7: TGA @ 100 ppm	0.93	14.32	33.99
B_8: TGA @ 200 ppm	1.12	15.54	40.53
SEm±	0.03	0.23	1.11
CD (P=0.05)	0.09	0.63	3.01
Interaction (D x B)			
SEm±	0.05	0.39	1.24
CD (P=0.05)	NS	NS	NS

Table 5. Effect of sowing at different thermal environments and foliar spray of bio-regulators on yield of wheat (on pooled basis)

Treatments	Yield (kg/ha)		
	Grain	**Straw**	**Biological**
Sowing at different thermal environments			
D_1: 22 ^oC	3582	4657	8240
D_2: 20 ^oC	3771	4880	8651
D_3: 18 ^oC	3437	4533	7970
SEm±	39	39	073
CD (P=0.05)	120	119	224
Foliar spray of bio-regulators			
B_1: Control	3230	4254	7485
B_2: Water spray	3358	4398	7756
B_3: SA @ 100 ppm	3432	4467	7900
B_4: SA @ 200 ppm	3874	4998	8873
B_5: TSA @ 100 ppm	3581	4703	8284
B_6: TSA @ 200 ppm	3790	4930	8720
B_7: TGA @ 100 ppm	3649	4804	8453
B_8: TGA @ 200 ppm	3858	4966	8824
SEm±	55	64	103
CD (P=0.05)	153	180	289
Interaction (D x B)			
SEm±	95	111	0.21
CD (P=0.05)	265	NS	NS

Table 6. Interaction effect of sowing at different thermal environments and foliar spray of bio-regulators on grain yield of wheat (on pooled basis)

Treatments	Sowing at different thermal environments		
Foliar spray of bio-regulators	**D_1: 22 °C**	**D_2: 20 °C**	**D_3: 18 °C**
B_1: Control	3072	3309	3062
B_2: Water spray	3440	3871	3053
B_3: SA @ 100 ppm	3460	3445	3393
B_4: SA @ 200 ppm	3843	4078	3774
B_5: TSA @ 100 ppm	3489	3805	3449
B_6: TSA @ 200 ppm	3894	3896	3582
B_7: TGA @ 100 ppm	3610	3656	3682
B_8: TGA @ 200 ppm	3851	4006	3647
SEm±	95		
CD (P=0.05)	265		

4. CONCLUSIONS

It may be concluded that wheat productivity is constrained with elevated temperature in semi-arid eastern plain zone may be effectively improved through application of salicylic acid @ 200 ppm at tillering and ear emergence stages of wheat along with sowing at prevailing mean temperature of 20°C.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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