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Plant growth regulators and their spray schedules affect growth, leaf area development and dry matter production under normal and late sown condition in wheat

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Abstract
Field experiment was carried out to investigate the plant growth regulators and their application schedules affect growth, leaf area development and dry matter production under normal and late sown condition in wheat during the winter (rabi) seasons of 2020–21 and 2021–22 at Research Farm, Seed Technology Research Centre, Department of Plant Physiology, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh. The experiment included three sowing dates (D1-15 November, D2-15 December, and D3 - 15 January), three spray schedulings at various stages (A1-Vegetative stage, A2-Anthesis stage, and A3-Vegetative + Anthesis stage), and seven plant growth regulators (H1: Cycocel @ 1000 ppm, H2: Salicylic acid @ 400 ppm, H3: Salicylic acid @ 800 ppm, KCl @ 1%, H4: Ascorbic acid @ 10 ppm, H5: Thiourea @ 400 ppm, H6: Water spray and H7: Control) were replicated three times in a split plot design to create 63 treatment combinations. The result showed that when wheat is delayed in being sown, it faces high temperatures during the grain developing stage, which has a negative impact on leaf area, leaf dry weight, stem food reserves, and total dry weight at various stages of growth of wheat. By increasing leaf area, leaf dry weight, stem food reserve and total dry weight at various growth stages of wheat, foliar spraying of salicylic acid @ 400 ppm and KCl @ 1% individually with two spray schedules (at vegetative stage and anthesis stage) application along with other plant growth regulators has the potential to improve wheat growth.

Keywords: Plant growth regulators, spray schedules, leaf area development, dry matter production

Introduction
Wheat (*Triticum aestivum* L.) is one of the major cereal crop belonging to Poaceae family which contributes about 30% of world's grain production and 50% of the world's grain trade (Akter and Islam 2017) [2] and is the staple food of more than 40 countries of the world as it provides about 20% of the total dietary calories and proteins worldwide (FAO STAT 2018) [9]. In India, wheat is grown in about 31.61 m ha area and Madhya Pradesh is the second major wheat producing state after Uttar Pradesh contributing 16.08% to the total production of India. It covers 6.39 m ha area with production of 17.62 MT and 2758 kg ha^{-1} productivity (Agriculture Statistics at a glance, 2021) [1]. However, this amount would not be enough to feed the increasing population and to satisfy the increased demand of 9 billion people by 2050, wheat production needs to be increased by 60%. This will require an increase of at least 1.6% yield annually (Narayanan *et al*. 2018) [17].

Change in weather conditions ultimately made extreme climate shift permanently and affect agriculture in the whole world (Barlow *et al* .2015) [5]. In India, late sowing of wheat is facing high temperature stress (Bhayal *et al*., 2022) [6], abnormal warming trends during reproductive stage which induces several alterations in physiological, biochemical and molecular components of wheat crop causing yield decrease, particularly in eastern and central India.

Elevated temperature between anthesis to maturity, affects grain yield of wheat due to reduction of vegetative growth period of crop by reducing the leaf area as well as reduction in dry matter partitioning as compared to normal conditions. Heat stress reduces the photo assimilate transport from current assimilation; under heat stress condition (Kumawat *et al*., 2023) [15], remobilization of reserve assimilates of stem and branches plays a very important role in determining plant growth and development.

Photo- assimilation is more likely to be yield-limiting under heat stress than in temperate environments, especially as stress typically intensifies during grain filling, when demand for assimilates is greater (Farooq *et al*., 2011) [10]. Heat stress also hastens senescence of photosynthetic leaf tissue and hydrolysis of macro molecules such as protein lipids etc. Heat stress also causes degradation of chlorophyll leading to reduction in leaf area affecting dry matter assimilation and yield.

Plant have complex stress tolerance mechanisms to detect external signals and can trigger an optimal response against stress conditions under the support of plant growth regulators that mainly control the defensive responses of plants by synergistic and antagonistic activities called signaling crosstalk. (Sabagh *et al*., 2021) [20]. Terminal heat stress in wheat can be managed by applying plant growth regulators which may be organic or inorganic in nature as they act as osmoregulators. PGR's play diverse role to regulate developmental processes of plant and signalling networks as they are involved either directly or indirectly in a wide range of biotic and abiotic stress responses and tolerance in plants. Therefore, it was hypothesized that plant growth regulator application mitigates heat stress effect by enhancing dry matter production and improving leaf area in wheat.

Material and Methods

The experiment was conducted at experimental farm of Seed Technology Research Unit, JNKVV, Jabalpur. For the present study, a field experiment was conducted in split plot design with three replications using Wheat genotype JW3382 (heat tolerant cultivar) and high temperature treatment was imposed by delaying the sowing dates i.e. D1-Normal sown (15th November), D2-Late sowing (15th December) and D3- Very late sowing (15th January) in 2020-21 and in 2021-22, respectively. In all conditions, different scheduling of spray i.e. at vegetative stage (A1), anthesis stage (A2) and vegetative and anthesis (A3) and different plant growth regulators were applied as treatments viz., H1-Cycocel @ 1000 ppm, H2- Salicylic acid @ 400 ppm, H3- Salicylic acid @ 800 ppm, H4- KCl @ 1%, H5-Ascorbic acid @ 10 ppm, H6-thiourea @ 400 ppm and T_7- foliar spray of water. Leaf area of plants was measured at 60, 75 and 90 DAS with the help of leaf area meter supplied by LI-COR Biosciences. Five plant samples were collected from each treatment and observations on dry matter of leaf, stem and total dry matter were recorded at 60, 75 and 90 DAS.

Table 1: Effect of sowing time, spray scheduling, plant growth regulator treatments on leaf area development of wheat

Treatment No.	Leaf Area 60 DAS			Leaf Area 75 DAS			Leaf Area 90 DAS		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Main Plot: 3 (Showing time)									
D1	1072.5	1101.4	1086.9	1345.3	1302.2	1323.7	982.1	1093.8	1037.9
D2	1029.7	1053.6	1041.7	1265.5	1271.4	1268.4	924.9	975.7	950.3
D3	960.9	983.1	972.0	1242.5	1196.8	1219.6	834.7	862.5	848.6
SEM±	5.52	6.19	4.85	7.70	1.57	3.55	9.30	8.66	7.73
CD (5%)	21.56	24.17	18.92	30.06	6.14	13.88	36.30	33.80	30.17
Sub Plot: 3 (Spray scheduling)									
A1	1027.5	1065.7	1046.6	1235.9	1216.5	1226.2	876.6	950.0	913.3
A2	990.5	992.6	991.6	1298.0	1268.2	1283.1	912.2	975.4	943.8
A3	1045.0	1079.8	1062.4	1319.3	1285.7	1302.5	952.9	1006.7	979.8
SEM±	5.31	5.26	3.70	4.01	4.07	2.82	7.37	2.79	4.06
CD (5%)	14.88	14.72	10.37	11.22	11.40	7.89	20.64	7.81	11.36
Sub Plot: 7 (Plant Growth Regulators)									
H1	1020.8	1015.6	1018.2	1282.3	1247.8	1265.1	928.1	988.1	958.1
H2	1030.6	1083.2	1056.9	1329.9	1299.6	1314.7	948.5	1016.5	982.5
H3	1025.6	1067.9	1046.7	1315.0	1304.0	1309.5	968.1	1024.0	996.0
H4	1036.4	1087.3	1061.8	1331.0	1310.6	1320.8	970.0	1014.2	992.1
H5	1020.4	1041.5	1030.9	1265.8	1256.7	1261.2	900.6	963.8	932.2
H6	1027.8	1054.4	1041.1	1284.6	1263.6	1274.1	944.9	985.6	965.2
H7	985.7	972.5	979.1	1182.4	1115.4	1148.9	737.1	849.2	793.1
SEM±	8.12	8.03	5.66	6.12	6.22	4.30	11.26	4.26	6.20
CD (5%)	22.73	22.49	15.84	17.14	17.41	12.05	31.53	11.93	17.36

Table 2: Effect of sowing time, spray scheduling, plant growth regulator treatments on leaf dry weight plant^{-1} of wheat

Treatment No.	Leaf Dry Weight 60 DAS (g plant^{-1})			Leaf Dry Weight 75 DAS (g plant^{-1})			Leaf Dry Weight 90 DAS (g plant^{-1})		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Main Plot: 3 (Showing time)									
D1	3.50	3.51	3.51	4.15	3.97	4.06	3.80	3.80	3.80
D2	3.47	3.52	3.50	3.94	3.77	3.86	3.62	3.61	3.62
D3	3.41	3.27	3.34	3.78	3.64	3.72	3.28	3.30	3.29
SEM±	0.010	0.003	0.005	0.019	0.032	0.025	0.068	0.058	0.061
CD (5%)	0.040	0.011	0.019	0.075	0.123	0.097	0.264	0.225	0.239
Sub Plot: 3 (Spray scheduling)									
A1	3.48	3.55	3.51	3.85	3.73	3.79	3.48	3.52	3.50
A2	3.43	3.25	3.34	3.93	3.80	3.86	3.64	3.57	3.60
A3	3.47	3.51	3.49	4.10	3.85	3.98	3.58	3.62	3.60
SEM±	0.013	0.014	0.009	0.035	0.033	0.030	0.033	0.033	0.032
CD (5%)	0.036	0.038	0.025	0.097	0.092	0.085	0.094	N/A	0.088
Sub Plot: 7 (Plant Growth Regulators)									
H1	3.42	3.42	3.42	3.97	3.76	3.87	3.67	3.68	3.68
H2	3.50	3.41	3.45	4.01	3.87	3.94	3.69	3.68	3.68
H3	3.44	3.49	3.46	4.09	3.92	4.00	3.78	3.76	3.77
H4	3.47	3.46	3.47	4.07	3.86	3.96	3.70	3.68	3.69
H5	3.50	3.39	3.45	3.87	3.78	3.83	3.50	3.52	3.51
H6	3.45	3.45	3.45	3.99	3.84	3.92	3.60	3.59	3.60
H7	3.42	3.42	3.42	3.71	3.52	3.61	3.03	3.07	3.05
SEM±	0.019	0.021	0.014	0.053	0.050	0.046	0.051	0.050	0.048
CD (5%)	0.054	0.059	N/A	0.149	0.141	0.130	0.143	0.141	0.135

Table 3: Effect of sowing time, spray scheduling, plant growth regulator treatments on Stem dry weight plant^{-1} of wheat

T. No.	Stem dry weight 60 DAS (g plant^{-1})			Stem dry weight 75 DAS (g plant^{-1})			Stem dry weight 90 DAS (g plant^{-1})		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Main Plot: 3 (Showing time)									
D1	6.39	7.08	6.73	**8.88**	8.95	8.92	6.50	6.13	6.31
D2	6.72	7.04	6.88	7.81	9.15	8.48	5.61	6.84	6.22
D3	6.32	6.71	6.51	7.31	8.02	7.66	4.65	7.34	5.99
SEM±	0.101	0.096	0.082	0.253	0.209	0.192	0.236	0.461	0.346
CD (5%)	N/A	N/A	N/A	0.988	0.815	0.751	0.920	N/A	N/A
Sub Plot: 3 (Spray scheduling)									
A1	6.80	7.01	6.91	7.68	8.36	8.02	4.79	6.24	5.51
A2	5.68	6.94	6.31	7.73	8.34	8.04	5.43	6.79	6.11
A3	6.93	6.88	6.91	8.58	9.41	9.00	6.54	7.28	6.91
SEM±	0.099	0.100	0.087	0.164	0.157	0.137	0.186	0.188	0.157
CD (5%)	0.276	N/A	0.245	0.458	0.441	0.383	0.521	0.527	0.440
Sub Plot: 7 (Plant Growth Regulators)									
H1	6.75	7.24	7.00	8.45	9.43	8.94	5.92	7.30	6.61
H2	6.37	7.06	6.72	8.18	8.53	8.35	5.97	7.01	6.49
H3	7.01	7.15	7.08	8.35	8.94	8.64	5.89	7.15	6.52
H4	6.70	7.17	6.94	8.68	9.40	9.04	5.52	7.85	6.69
H5	6.18	6.88	6.53	7.53	8.14	7.83	5.46	6.56	6.01
H6	6.78	7.12	6.95	8.18	9.08	8.63	5.49	6.99	6.24
H7	5.51	5.99	5.75	6.62	7.42	7.02	4.85	4.50	4.68
SEM±	0.151	0.153	0.133	0.250	0.240	0.209	0.284	0.288	0.240
CD (5%)	0.422	0.429	0.374	0.700	0.673	0.584	N/A	0.805	0.673

Table 4: Effect of sowing time, spray scheduling, plant growth regulator treatments on total dry matter accumulation plant^{-1} of wheat

Treatment No.	TDM 60 DAS (g plant^{-1})			TDM 75 DAS (g plant^{-1})			TDM 90 DAS (g plant^{-1})		
	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled	2020-21	2021-22	Pooled
Main Plot: 3 (Showing time)									
D1	14.88	15.61	15.25	24.50	26.06	25.28	31.57	33.04	32.30
D2	14.42	14.90	14.66	23.54	25.12	24.33	29.16	31.87	30.52
D3	13.53	13.51	13.52	21.32	22.89	22.11	26.52	29.40	27.96
SEM±	0.128	0.089	0.090	0.238	0.178	0.185	0.433	0.609	0.519
CD (5%)	0.500	0.347	0.350	0.930	0.693	0.724	1.691	2.379	2.027
Sub Plot: 3 (Spray scheduling)									
A1	14.66	15.09	14.88	22.46	24.15	23.31	27.27	30.40	28.83
A2	13.40	14.11	13.76	22.79	24.35	23.57	29.19	31.29	30.24
A3	14.77	14.82	14.80	24.12	25.56	24.84	30.80	32.62	31.71
SEM±	0.092	0.101	0.090	0.156	0.140	0.128	0.188	0.209	0.182
CD (5%)	0.258	0.283	0.251	0.438	0.393	0.359	0.526	0.584	0.511
Sub Plot: 7 (Plant Growth Regulators)									
H1	14.44	14.94	14.69	23.54	25.47	24.51	29.84	32.75	31.30
H2	14.30	14.71	14.50	23.69	24.92	24.31	30.27	32.80	31.53
H3	14.75	15.03	14.89	23.89	25.45	24.67	30.09	32.92	31.50
H4	14.55	14.98	14.77	24.09	25.74	24.92	30.60	33.59	32.10
H5	14.12	14.49	14.31	22.49	24.24	23.37	27.98	29.79	28.89
H6	14.57	14.90	14.73	23.37	25.34	24.36	29.13	32.11	30.62
H7	13.21	13.67	13.44	20.79	21.65	21.22	25.68	26.09	25.89
SEM±	0.141	0.154	0.137	0.239	0.214	0.196	0.287	0.319	0.279
CD (5%)	0.395	0.432	0.384	0.669	0.600	0.549	0.804	0.892	0.780

Result and Discussions

Leaf area of wheat crop at different growth stages were differed significantly due to date of sowing, spray schedule of growth regulators. The maximum leaf area of crop was increased from 60 DAS to 75 DAS stage during both the year (2020-21 and 2021-22) and declined thereafter, towards maturity. It might be due to increases in rate of leaf senescence, reduced leaf lamina and leaf fall and caused significant reduction in leaf area after 75 DAS in wheat crop (Kumawat *et al*., 2021) [14]. Analysis of variance of pooled data revealed that the normal date of sowing (D1) noted maximum leaf area 1086.9, 1323.7, 1037.9 over late sowing and very late sown crop at 60 DAS, 75 DAS and 90DAS, respectively. The significant reduction in leaf area under delay in sowing was recorded at compare to normal sowing. It might be due to under late sown crop face high temperature that reduced leaf lamina and leaf sheath dry weight in wheat as compared to normal sowing crop. Analysis of variance of pooled data revealed that the application of PGR's at both Vegetative and Anthesis stage (A3) Spray schedules were recorded maximum leaf area 1062.4, 1302.5, 979.8 over Vegetative stage (A1) and Anthesis stage (A2) at 60 DAS, 75 DAS and 90DAS, respectively. Foliar application of different bio regulators enhance the leaf area of wheat at compare to water spray. KCl @ 1% (H4) recorded maximum leaf area 1061.8 and 1320.8 over others at 60 DAS, 75 DAS respectively. Salicylic acid application @ 800 ppm (H3) recorded maximum leaf area 996.0 over others treatments at 90 DAS stage of wheat. Salicylic acid application in wheat crop had enhance of leaf area under normal and under abiotic stresses conditions was also reported in wheat (Singh *et al*., 2021 [21] and Jatana *et al*., 2022) [12] and in Chickpea (Debnath *et al*., 2022) [7]

Leaf dry weight and stem dry weight of wheat crop at different growth stages were differed significantly due to date of sowing, spray schedule of growth regulators. Analysis of variance of pooled data revealed that the normal date of sowing (D1) noted maximum leaf dry weight and stem dry weight over late sowing and very late sown crop at 60 DAS, 75 DAS and 90 DAS, respectively. Late sowing condition induced heat stress reduces the new laves development, reduces leaf area expansion. Significant reduction was recorded in dry weight of the intact plant vegetative organs (stems + leaves of plant) during high temperature stress conditions, it might be due to translocation of non-structural carbohydrates and photosynthetes to the reproductive organs (developing kernels) (Plaut *et al*., 2004) [19]. Prolonged heat stress was also significantly reduced leaf photosynthesis rate are associated with increase the rate of leaf senescence and protein denaturation which causes reduction in dry weight of leaves (Debnath *et al*., 2022) [7]. Analysis of variance of pooled data revealed that the application of KCl @ 1% (H4) recorded maximum leaf dry weight (3.47) over others at 60 DAS and Salicylic acid application @ 800 ppm (H3) recorded maximum leaf dry weight (4.0), (3.77) over others treatments at 75 DAS and 90 DAS stage of wheat respectively. Salicylic acid and KCl application had potential to alleviate the effect of high temperature stress and also enhances dry matter production under stress and non-stress condition (Patel *et al*., 2012 [18] and Kumar *et al*., 2020) [13]

Total dry matter accumulation plant-1 of wheat crop at different growth stages were differed significantly due to date of sowing, spray schedule of growth regulators and kind of growth regulators individually. Dry matter production is the outcome of the interaction of various crop growth factors and reflects the growth and metabolic efficiency of plants. In present investigation resulted that the increase in plant dry matter production with increasing trend up to 90 DAS after sowing. Mean dry matter production of different growth stages in case of Normal sowing was significantly higher than late and very late sown wheat might be due to acquired maximum growth period and higher photosynthetic efficiency in normal sown crop also had maximum leaf area and maximum number of tillers. Reduction in dry matter accumulation in delayed sowing may have reduced vegetative growth as well as reproductive growth of the crop due to under high temperature during the later stages plants have less photosynthetic efficiency leading to lower dry matter production. These results are in conformed to similar findings of Ghosh *et al*. (2000) [11], Dogiwal *et al*. (2013) [8], Mukherjee (2012) [16]. Among the PGRs application, significantly higher mean dry matter production at different growth interval was recorded with the application of KCl @ 1% was maximum dry matter accumulation at par with salicylic acid @ 800 ppm application. The adequate foliar application of PGRs had increase the chlorophyll content of leaf this allowed the plant stimulated the rapid rate of photosynthesis activity and in turn produced more dry matter accumulation of plant. Also, the application of KCl foliar application increase vegetative growth and leaf area duration. Andersen *et al*., 1992 [4] also confirmed results with concluded that the Increase the rate of KCl applications under normal and drought stress condition significantly increased rate of growth of the vegetative parts of the crop and high K application the leaf area increased up to 26% at anthesis, and top dry matter accumulation increased up to 15% between anthesis and milk-ripe stages of growth, resulting in about 10% higher straw yield at final harvest. The results are close conformity with the findings of Amin *et al.* (2013) [3]

Conclusion

The different sowing dates have directly impact on growth and photo assimilate partitioning of wheat, delayed in sowing of wheat facing high temperature during grain developing stage which have adverse effect on green leaf area, leaf dry weight, stem food reserve and total dry weight at different growth stages of wheat. Foliar spraying of salicylic acid @ 400 ppm and KCl @ 1% individually with two spray schedules (at vegetative stage and anthesis stage) application along with other plant growth regulators at different growth stages have potential to enhance the growth of wheat by improving of leaf area, leaf dry weight, stem food reserve, total dry weight at different growth stages of wheat.

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