PLANT SCIENCE TODAY
Vol 12(sp4): 01-08
https://doi.org/10.14719/pst.9730

eISSN 2348-1900

RESEARCH ARTICLE

Impact of seed priming on heat stress mitigation in wheat (*Triticum aestivum* L.)

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Received: 31 May 2025; Accepted: 18 September 2025; Available online: Version 1.0: 17 November 2025

Cite this article: Sondarva JR, Patel JB, Savaliya DV, Babariya CA. Impact of seed priming on heat stress mitigation in wheat (*Triticum aestivum* L.). Plant Science Today. 2025;12(sp4):01-08. https:/doi.org/10.14719/pst.9730

Abstract

Heat stress is one of the most critical challenges in wheat cultivation, particularly under late sowing, where rising temperatures directly reduce productivity and threaten food security. Identifying simple and affordable strategies to safeguard yields is therefore urgent and essential. This experiment evaluated six wheat varieties across three consecutive growing seasons using nine different seed priming approaches. The results consistently demonstrated that seed priming enhanced crop establishment, plant vigour and yield under heat-stressed conditions. Among the varieties, GW 366 showed the highest tolerance, while seed priming with salicylic acid @ 50 ppm proved to be the most effective treatment. Together, this combination delivered significantly higher yields and improved seed quality compared to untreated controls. Its benefits were attributed to multiple physiological mechanisms: preservation of chlorophyll and photosystem II activity, improved dry matter remobilization to grains, enhanced antioxidant defence, increased accumulation of Osmo protectants such as proline and modulation of ethylene production to maintain photosynthetic efficiency under stress. This study confirms that seed priming with salicylic acid (50 ppm) is a low-cost and scalable method to mitigate heat stress in wheat. For farmers, this practice can translate into yield gains of up to 10-15 %, which, at a regional scale, may contribute by giving additional revenue and reduce the economic risks associated with late sowing. Environmentally, the method is safe, does not require additional inputs and promotes sustainable intensification of wheat production. These findings offer a practical breakthrough for ensuring food security and resilience in wheat-based farming systems under changing climates.

Keywords: heat stress; seed priming; salicylic acid; wheat

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally, with one third of the world's population relying on it as a primary food source. It is a temperature-sensitive, long-day crop that is well-suited for temperate climates. However, climate change is intensifying the frequency and severity of heat waves, making wheat production more vulnerable than ever. The dual pressures of rising population and climate change have forced farmers to expand wheat cultivation into warmer regions, where the crop is increasingly exposed to heat stress. Under changing climate scenario, abiotic stresses are serious threat in crop production (1).

In India, wheat is cultivated across tropical and subtropical regions, with the optimal sowing window in North-Western and Central India being the third week of November. The ideal temperature for all physiochemical processes of wheat, from vegetative to reproductive stage, is 20 °C or below (2). A decrease in yield of 0.7 % per day occurs when sowing is delayed since the reproductive and ripening stages of late sown wheat crop are usually subjected to high temperature stress in March and April (3). A rise in temperature by 1 °C may lead to a reduction in grain weight of as much as 4 mg (4). Therefore, heat stress during various stages of crop development can speed up the vegetative growth, shortens the timing of developmental phases and ultimately decrease the overall yield. It significantly affects the quality of seeds and seed health status of cereals, primarily due to their influence on nutrient uptake, assimilates supply, partitioning and remobilization of nutrients. These shifts underscore the urgent need for adaptive agronomic practices to sustain wheat production under a changing climate.

Among the promising approaches, pre-sowing seed priming has gained attention as a low-cost and environmentally safe method to improve germination, seedling vigour and stress resilience in crops (5). Priming has been shown to mitigate heat stress by enhancing antioxidant activity, regulating key enzymes involved in osmolyte and proline biosynthesis, stabilizing cellular membranes and maintaining photosynthetic efficiency (6). These physiological adjustments collectively improve growth and yield stability under elevated temperatures. It has been reported that priming enhances days to emergence, anthesis and increases dry matter production. Wheat seeds primed with 0.3 % P_2O_5 gave less time to anthesis and yield enhanced with each increment of priming (7). Various morphological traits in wheat *viz.*, tiller number, spike length, number of grains per spike, 1000 grain weight and seed yield per plot increased because of seed priming (8).

Therefore, the present study was undertaken as the first multi-season field experiment to evaluate the efficacy of different seed priming treatments in mitigating late-sown heat stress in wheat. It was hypothesized that pre-sowing seed priming can effectively mitigate terminal heat stress in wheat by enhancing germination, enzymatic antioxidant defence, osmotic adjustment and membrane stability, thereby sustaining grain filling and yield. Specifically, we expected that priming treatments (P_2-P_9) would significantly outperform the unprimed control (P_1) in terms of yield, yield components and seed quality. Varietal differences would be evident, with GW 366 exhibiting superior heat tolerance and significant variety × priming interaction would reveal the most resilient combination under heat stress. Finally, priming would prove economically viable. Collectively, the study aimed to demonstrate that seed priming is not only an environmentally adaptive technology but also a commercially profitable strategy for sustaining wheat productivity under climate-induced heat stress.

Materials and Methods

Geographically Junagadh (Gujarat - India) is situated at 21.5°N latitude and 70.5°E longitude with an altitude of 60 m above mean sea level on the western side at the foothill of mountain Girnar Sierra. The average minimum and maximum temperature ranges between 19.8 °C and 33.06 °C, respectively. Soils are medium black having average depth of 45 cm. So far NPK status is concerned, the soil contains low to medium Nitrogen and Phosphorus and medium to high Potash. The pH of soils is 7.5 to 8.0 and EC value is around 0.35 ds/m.

Genetically pure seeds of different wheat varieties were obtained from Wheat Research Station, Junagadh Agricultural University, Junagadh. This experiment was carried out at *Sagdividi* farm, Department of Seed Science and technology, JAU, Junagadh under late sown conditions for three consecutive *rabi* seasons from 2020-21 to 2022-23. The experiential material comprised of six varieties of wheat (V_1 = GW 496, V_2 = GW 451, V_3 = GJW 463, V_4 = GW 173, V_5 = Lok 1 and V_6 = GW 366) and nine priming treatments (P_1= Absolute control, P_2= Hydropriming (distilled water), P_3 = Osmo priming (PEG-6000) @ 10 %, P_4 = Hormonal Priming-GA_3@ 50 ppm, P_5 = Hormonal Priming-IAA @ 100 ppm, P_6= Hormonal Priming with Salicylic acid @ 50 ppm, P_7= Halo priming of KH_2PO_4 @ 1 %, P_8= Halo priming of KCl @ 2.5 % and P_9= Halo priming of $CaCl_2$ @ 2 %) were evaluated as second factor. The chemicals used in this experiment are presented in table below. Seeds were soaked in different priming solutions for 14 hrs at room temperature. Afterward, the seeds were taken out of the solutions and dried in the shade at room temperature until they returned to their original moisture content.

Following field observations were recorded for the study: field emergence (%), days to flowering, days to maturity, grain filling period, number of productive tillers per plant, spike length (cm), number of spikelets per spike, number of grains per spike, 1000 grain weight, grain yield per plant (g), biological yield per plant (g), harvest index (%), chlorophyll content (SPAD value), canopy temperature depression. Observations were recorded at maturity stage of plant growth on all the quantitative characters.

The laboratory observations *viz*., germination (%), Seed vigour index I, Seed vigour index II and Seed moisture content (%) were measured using harvested seeds of different varieties and treatments and were analyzed employing Randomized Block Design (Factorial) as the method suggested by Cochran and Cox (9) and ANOVA was used to assess treatment effects.

Results and Discussion

Wheat varieties and priming treatments had a significant influence on grain yield per plant (Table 2). Over the course of three years and through a pooled analysis, GW 366 produced the highest grain yield per plant, followed by Lok 1 and GW 173, with GW 496 being the poorest performer. Among the priming treatments, a solution of salicylic acid @ 50 ppm gave the highest grain yield per plant, which was statistically at par with 100 ppm IAA and significantly superior to unprimed control. The interaction effect of variety and priming treatments for grain yield per plant was non-significant for individual years and pooled results. Both genetic background and pre-sowing treatments are jointly responsible for determining resilience in late-sown, heat-stressed conditions.

Biological yield exhibited a similar pattern (Table 3). GW 366 consistently produced the highest biological yield per plant, followed by Lok 1 and GW 173, with GW 496 displaying the lowest biological yield per plant. Salicylic acid @ 50 ppm primed seeds achieved the highest biological yield per plant, being statistically at par with IAA (100 ppm). The interaction between variety and priming was significant for individual years and in pooled results. The combination GW 366 (V_6) × KCl (2.5 %) (P_8) consistently recorded the highest biological yield per plant across all years and in pooled analysis (Table 4). Conversely, the combination GW 173 (V_4) × GA_3 (50 ppm) (P_4) produced the lowest biological yield per plant across all years and in pooled results.

Growth and yield attributes of wheat including field emergence (%), days to flowering, days to maturity, grain filling period, number of productive tillers per plant, spike length (cm), number of spikelets per spike, number of grains per spike, 1000 grain weight, harvest index (%), chlorophyll content (SPAD value) and canopy temperature depression) were significantly affected by different varieties and seed priming treatments showed in Table 5 to 7. Among the different varieties of wheat, field emergence and chlorophyll content was found non-significant.

Table 1. Chemicals used in priming treatments with manufacturer's name and its code

Chemical Name	Manufacturer's name	Unique code for chemical purchase
Polyethylene Glycol 6000 Powder (PEG 6000)	Sisco Research Laboratories Pvt. Ltd. (SRL)	49194
Gibberellic Acid (GA3), 90 %	Sisco Research Laboratories Pvt. Ltd. (SRL)	95110
Indole-3-Acetic Acid (IAA) pure, 98 %	Sisco Research Laboratories Pvt. Ltd. (SRL)	88318
Salicylic Acid pure, 99 %	Sisco Research Laboratories Pvt. Ltd. (SRL)	11453
Potassium Dihydrogen Orthophosphate pure, 99 %	Sisco Research Laboratories Pvt. Ltd. (SRL)	52403
Potassium Chloride ACS, 99.5 %	Sisco Research Laboratories Pvt. Ltd. (SRL)	38630
Calcium Chloride Fused pure, 90-95 %	Sisco Research Laboratories Pvt. Ltd. (SRL)	84336

Table 2. Effect of seed priming treatments on grain yield per plant (g) in wheat

Treatments	2020-21	2021-22	2022-23	Pooled
Variety				
V_1	5.80	5.72	5.79	5.77
V_2	5.95	6.27	6.14	6.12
V_3	5.69	6.24	5.99	5.97
V_4	6.36	6.37	6.40	6.38
V_5	7.05	6.44	6.77	6.75
V_6	8.02	7.13	7.61	7.59
S.Em±	0.26	0.14	0.25	0.13
C.D. at 5 %	0.72	0.39	0.71	0.36
Priming treatments				
P_1	7.12	6.81	7.00	6.98
P_2	4.70	5.28	5.02	5.00
P_3	6.86	6.53	6.72	6.70
P_4	5.65	6.07	5.89	5.87
P_5	7.75	6.99	7.40	7.38
P_6	8.34	7.29	7.85	7.83
P_7	6.46	6.28	6.40	6.38
P_8	6.17	6.16	6.19	6.17
P_9	5.26	5.84	5.58	5.56
S.Em±	0.32	0.17	0.31	0.16
C.D. at 5 %	0.89	0.47	0.87	0.44
V X P				
S.Em±	0.77	0.41	0.76	0.39
C.D. at 5 %	NS	NS	NS	NS
Y X V				
S.Em±				0.22
C.D. at 5 %				NS
Y X P				
S.Em±				0.27
C.D. at 5 %				NS
Y X V X P				
S.Em±				0.67
C.D. at 5 %				NS
C.V. %	20.68	11.25	20.60	18.08

Table 3. Effect of seed priming treatments on biological yield per plant (g) in wheat

Treatments	2020-21	2021-22	2022-23	Pooled
Variety				
V_1	20.91	18.99	19.98	19.96
V_2	21.52	19.02	20.30	20.28
V_3	21.87	20.17	21.05	21.03
V_4	21.51	17.86	19.72	19.70
V_5	26.34	22.74	24.57	24.55
V_6	29.33	24.41	26.90	26.88
S.Em±	0.55	0.47	0.39	0.28
C.D. at 5 %	1.56	1.33	1.10	0.77
Priming treatments				
P_1	25.39	22.02	23.74	23.72
P_2	20.70	18.43	19.59	19.57
P_3	23.28	20.01	21.68	21.66
P_4	21.01	18.35	19.71	19.69
P_5	24.75	20.93	22.87	22.85
P_6	27.24	23.69	25.50	25.48
P_7	24.98	21.65	23.34	23.32
P_8	23.28	20.63	21.99	21.97
P_9	21.61	19.06	20.36	20.34
S.Em±	0.68	0.58	0.48	0.34
C.D. at 5 %	1.91	1.63	1.35	0.94
V X P				
S.Em±	1.66	1.42	1.18	0.83
C.D. at 5 %	4.67	3.99	3.30	2.31
Y X V				
S.Em±				0.48
C.D. at 5 %				NS
Y X P				
S.Em±				0.59
C.D. at 5 %				NS
Y X V X P				
S.Em±				1.43
C.D. at 5 %				NS
C.V. %	12.23	12.00	9.23	11.26

Table 4. Interaction effect of varieties and seed priming treatments on biological yield per plant (g) in wheat

Y X V X P						
2020-21	**V_1**	**V_2**	**V_3**	**aV_4**	**V_5**	**V_6**
P_1	16.49	24.34	23.19	24.02	27.19	37.09
P_2	22.21	13.31	15.06	26.42	27.79	19.41
P_3	20.57	19.38	28.38	24.82	20.34	26.18
P_4	11.73	30.35	13.06	11.34	29.52	30.04
P_5	29.03	15.74	27.32	17.62	24.51	34.27
P_6	28.83	28.36	19.52	21.57	28.54	36.62
P_7	17.27	25.27	22.63	25.91	37.39	21.42
P_8	16.72	19.84	21.59	17.74	23.92	39.87
P_9	25.36	17.13	26.10	24.17	17.84	19.05
2021-22	**V_1**	**V_2**	**V_3**	**V_4**	**V_5**	**V_6**
P_1	16.45	20.86	21.10	20.04	24.48	29.22
P_2	20.78	12.23	15.01	21.99	23.30	17.24
P_3	17.96	18.15	25.39	17.57	18.21	22.79
P_4	12.13	24.92	13.85	10.34	23.97	24.89
P_5	23.02	14.95	24.84	15.19	21.09	26.47
P_6	27.17	24.74	19.01	17.44	23.86	29.96
P_7	15.55	23.03	17.81	22.92	31.12	19.46
P_8	15.06	18.07	21.01	16.43	21.58	31.65
P_9	22.82	14.23	23.48	18.80	17.04	17.99
2022-23	**V_1**	**V_2**	**V_3**	**V_4**	**V_5**	**V_6**
P_1	16.50	22.63	22.18	22.06	25.86	33.18
P_2	21.52	12.80	15.06	24.24	25.58	18.36
P_3	19.30	18.79	26.92	21.22	19.31	24.52
P_4	11.96	27.67	13.49	10.87	26.77	27.49
P_5	26.06	15.37	26.11	16.44	22.83	30.40
P_6	28.03	26.58	19.29	19.53	26.23	33.32
P_7	16.44	24.18	20.25	24.44	34.28	20.47
P_8	15.92	18.98	21.33	17.12	22.78	35.79
P_9	24.12	15.71	24.82	21.51	17.47	18.55
S.Em±				1.43		
C.D. at 5 %				NS		
Pooled	**V_1**	**V_2**	**V_3**	**V_4**	**V_5**	**V_6**
P_1	16.48	22.61	22.16	22.04	25.84	33.16
P_2	21.50	12.78	15.04	24.22	25.56	18.34
P_3	19.28	18.77	26.90	21.20	19.29	24.50
P_4	11.94	27.65	13.47	10.85	26.75	27.47
P_5	26.04	15.35	26.09	16.42	22.81	30.38
P_6	28.01	26.56	19.27	19.51	26.21	33.30
P_7	16.42	24.16	20.23	24.42	34.26	20.45
P_8	15.90	18.96	21.31	17.10	22.76	35.77
P_9	24.10	15.69	24.80	21.49	17.45	18.53
C.V. %				11.26		

Table 5. Effect of seed priming treatments on field emergence (%), days to flowering, days to maturity and grain filling period in wheat (pooled basis)

Treatments	Field emergence (%)	Days to flowering	Days to maturity	Grain filling period
Variety				
V_1	91.32	51.08	87.98	30.61
V_2	90.36	54.07	89.77	28.97
V_3	91.32	57.28	95.65	31.40
V_4	90.60	47.87	88.82	33.69
V_5	90.96	48.89	88.84	33.23
V_6	89.95	51.87	90.96	33.45
S.Em±	0.74	0.86	0.67	0.75
C.D. at 5 %	NS	2.40	1.87	2.08
Priming treatments				
P_1	90.54	51.79	90.96	32.33
P_2	90.91	51.72	89.97	31.54
P_3	90.70	51.75	89.96	31.69
P_4	91.28	52.37	89.59	30.94
P_5	91.02	51.42	90.90	33.07
P_6	90.83	52.45	90.25	31.24
P_7	90.54	51.08	90.69	32.59
P_8	90.33	52.18	90.89	32.31
P_9	90.63	51.82	89.81	31.31
S.Em±	0.91	1.06	0.82	0.92
C.D. at 5 %	NS	NS	NS	NS
V X P				
S.Em±	2.22	2.59	2.02	2.24
C.D. at 5 %	NS	NS	NS	NS
Y X V				
S.Em±	1.28	1.49	1.17	1.29
C.D. at 5 %	NS	NS	NS	NS
Y X P				
S.Em±	1.57	1.83	1.43	1.58
C.D. at 5 %	NS	NS	NS	NS
Y X V X P				
S.Em±	3.84	4.48	3.50	3.88
C.D. at 5 %	NS	NS	NS	NS
C.V. %	7.33	7.97	6.70	8.13

Table 6. Effect of seed priming treatments on number of productive tillers per plant, spike length (cm), number of spikelets per spike and number of grains per spike in wheat

Treatments	Number of productive tillers per plant	Spike length (cm)	Number of spikelets per spike	Number of grains per spike
Variety				
V_1	4.67	7.47	13.27	30.87
V_2	5.43	6.89	13.00	31.52
V_3	5.26	7.92	14.59	31.27
V_4	5.38	6.55	12.83	29.62
V_5	6.08	7.30	12.73	30.11
V_6	5.54	6.72	12.82	30.55
S.Em±	0.17	0.10	0.21	0.48
C.D. at 5 %	0.46	0.28	0.60	1.33
Priming treatments				
P_1	5.47	7.18	13.68	31.25
P_2	5.33	6.96	13.17	30.80
P_3	5.49	7.18	13.27	31.06
P_4	4.83	7.06	12.85	30.44
P_5	5.65	7.19	12.76	29.68
P_6	5.73	7.24	13.54	32.09
P_7	5.38	7.18	12.95	30.74
P_8	5.55	7.24	13.64	29.80
P_9	5.10	7.03	13.01	30.06
S.Em±	0.20	0.12	0.26	0.58
C.D. at 5 %	NS	NS	NS	NS
V X P				
S.Em±	0.50	0.31	0.64	1.43
C.D. at 5 %	NS	NS	NS	NS
Y X V				
S.Em±	0.29	0.18	0.37	0.83
C.D. at 5 %	NS	NS	NS	NS
Y X P				
S.Em±	0.35	0.22	0.46	1.01
C.D. at 5 %	NS	NS	NS	NS
Y X V X P				
S.Em±	0.87	0.53	1.12	2.48
C.D. at 5 %	NS	NS	NS	NS
C.V. %	10.89	12.84	14.63	13.98

Table 7. Effect of seed priming treatments on 1000 grain weight, harvest index (%), chlorophyll content (SPAD value) and canopy temperature depression in wheat

Treatments	1000 grain weight	Harvest index (%)	Chlorophyll content (SPAD value)	Canopy temperature depression
Variety				
V_1	40.47	31.02	46.13	6.20
V_2	38.70	31.89	45.48	6.48
V_3	36.52	29.99	47.31	5.80
V_4	38.31	34.37	45.59	7.09
V_5	45.18	28.32	45.82	5.91
V_6	46.32	29.29	47.34	5.58
S.Em±	0.68	0.66	0.64	0.35
C.D. at 5 %	1.89	1.83	NS	0.97
Priming treatments				
P_1	40.51	30.32	46.79	5.77
P_2	40.65	27.20	45.44	6.57
P_3	40.31	31.48	46.49	6.44
P_4	40.70	34.93	46.43	6.24
P_5	41.05	34.34	46.61	5.55
P_6	41.56	31.96	46.84	6.63
P_7	41.96	28.76	45.57	6.28
P_8	40.50	29.66	45.88	6.15
P_9	41.02	28.67	46.48	5.96
S.Em±	0.83	0.81	0.79	0.43
C.D. at 5 %	NS	2.25	NS	NS
V X P				
S.Em±	2.04	1.98	1.93	1.04
C.D. at 5 %	NS	5.50	NS	NS
Y X V				
S.Em±	1.18	1.14	1.11	0.60
C.D. at 5 %	NS	NS	NS	NS
Y X P				
S.Em±	1.44	1.40	1.36	0.74
C.D. at 5 %	NS	NS	NS	NS
Y X V X P				
S.Em±	3.54	3.43	3.33	1.80
C.D. at 5 %	NS	NS	NS	NS
C.V. %	8.97	15.26	12.48	16.38

Variety GJW 463 recorded significantly the highest days to flowering (57.28), days to maturity (95.65), spike length (7.92 cm) and number of spikelets per spike (14.59). Variety GW 173 showed significantly the lowest days to flowering (47.87 days), shortest spike length (6.55 cm) and the highest harvest index (34.37 %), but it also maintained the longest grain filling period (33.69 days), which was at par with variety GW 366 (33.45 days) and Lok 1 (33.23 days). Although, it produced the lowest number of grains per spike (29.62). Variety GW 496 had taken the lowest days to maturity (87.98 days) and had the fewest productive tillers per plant, suggesting it had a weaker adaptation to heat stress. Lok 1 had the highest number of productive tillers per plant (6.08) but it had the lowest number of spikelets per spike (12.73) and harvest index (28.32 %). GW 451 showed the highest number of grains per spike (31.52) which was at par with variety GJW 463 (31.27), GW 496 (30.87) and GW 366 (30.55). GW 451 also recorded the shortest grain filling period (28.97 days), implying faster reproductive development under stress conditions. GW 366 demonstrated the highest 1000-grain weight (46.32 g) and the smallest canopy temperature depression (5.58).

Different seed priming treatments exhibited non-significant difference for all growth attributes except harvest index for pooled result. Significantly the highest harvest index was recorded in seed primed with GA_3 @ 50 ppm (34.93 %) and it was at par with seed primed with IAA @ 100 ppm (34.34 %). The lowest harvest index was recorded in hydropriming (27.20 %). Interaction between varieties and seed priming treatments was found non-significant for all the growth attributes except harvest index in pooled results.

Various other morphological parameters such as number of seeds per spike, thousand grain weight and seed yield per plot was also higher in primed seed as compared to control. The beneficial impact of priming treatments was observed on grain yield and various traits of bread wheat (10). Seed priming resulted in a greater number of productive tillers per unit area, spike length, number of grains per spike, thousand grain weight and enhanced the grain yield (11). This is due to seed priming notably reducing the time needed to begin emergence, time to 50 % emergence, mean emergence time and enhancing energy of emergence in seeds collected from all past sowing dates. Seed priming treatment gave better field emergence in plant (12). Plant height, yield contributing traits and seed quality parameters increased because of seed priming (13).

SA priming enhances early germination and seedling establishment by improving enzymatic activity and reserve mobilization (14, 15). It also bolsters the antioxidant defence system by elevating superoxide dismutase, catalase and ascorbate peroxidase activities, thereby reducing ROS build-up and lipid peroxidation aiding in membrane stability (16). Additionally, SA preserves photosynthetic pigments and osmotic balance through elevated soluble sugars and pigments, which helps maintain photosynthesis under heat stress (17, 18). It further acts as a signalling molecule, inducing heat-protective changes in proline metabolism and restricting ethylene synthesis, thus reinforcing cellular defence (18). Together, these integrated responses improve vegetative growth and sustain reproductive performance reducing floret abortion, extending grain filling and enhancing seed yield under heat stress.

The freshly harvested seeds from all priming treatment were analyzed for their impact on seed quality parameters. Among the different varieties of wheat, germination per cent showed non-significant difference for pooled results. While seed vigour index I, seed vigour index II and seed moisture content was recorded significant effect for pooled results (Table 8). Significantly highest

Table 8. Effect of seed priming treatments on germination (%), seed vigour index I, seed vigour index II and seed moisture content (%) in wheat

Treatments	Germination (%)	Seed vigour index I	Seed vigour index II	Seed moisture content (%)
Variety				
V_1	97.44	2800.76	247.97	6.79
V_2	96.28	2725.07	227.02	6.84
V_3	96.79	2892.49	241.95	5.90
V_4	96.88	2776.98	237.81	5.56
V_5	96.35	2786.35	280.86	6.11
V_6	96.95	2872.68	295.33	6.06
S.Em±	0.43	32.71	4.43	0.26
C.D. at 5 %	NS	91.00	12.33	0.71
Priming treatments				
P_1	93.92	2661.99	246.54	6.36
P_2	96.58	2637.24	252.51	6.06
P_3	96.84	2806.70	255.55	6.26
P_4	97.61	2896.00	258.56	6.00
P_5	97.40	2902.97	256.02	6.20
P_6	97.35	2845.55	253.74	6.72
P_7	96.65	2865.14	255.17	6.01
P_8	97.16	2847.35	258.61	6.09
P_9	97.51	2818.53	259.71	6.18
S.Em±	0.52	40.06	5.43	0.31
C.D. at 5 %	1.45	111.45	NS	NS
V X P				
S.Em±	1.28	98.12	13.30	0.77
C.D. at 5 %	NS	NS	NS	NS
Y X V				
S.Em±	0.74	56.65	7.68	0.44
C.D. at 5 %	NS	NS	NS	NS
Y X P				
S.Em±	0.90	69.38	9.40	0.54
C.D. at 5 %	NS	NS	NS	NS
Y X V X P				
S.Em±	2.21	169.94	23.03	1.33
C.D. at 5 %	NS	NS	NS	NS
C.V. %	3.96	4.41	5.78	7.06

seed vigour index I was recorded in variety GJW 463 (2892.49) which was at par with variety GW 366 (2872.68) and the lowest seed vigour index I was recorded in variety GW 451 (2725.07). Significantly the highest and lowest seed vigour index II was recorded in variety GW 366 (295.33) and GW 451 (227.02), respectively. Significantly the minimum seed moisture content was recorded in variety GW 173 (5.56 %) and which was at par with GJW 463 (5.90 %), GW 366 (6.06 %) and Lok 1 (6.11 %) and the maximum seed moisture content was recorded in variety GW 451 (6.84 %).

Different seed priming treatments exhibited non-significant difference for seed vigour index II and seed moisture content while germination per cent and seed vigour index II recorded significant result. Among the different priming treatments, significantly the highest germination was recorded in seeds primed with GA_3 @ 500 ppm (97.61 %) which was at par with all primed treatments except control. Seeds primed with IAA @ 100 ppm recorded highest seed vigour index I (2902.97) which was at par with all other treatments except control and hydropriming. The interaction was found significant for all seed quality attributes in pooled results.

The enhancement of seed quality characteristics takes place because priming triggers various biochemical modifications in the seed that are necessary to initiate the germination process. This includes the breaking of dormancy, hydrolysis or mobilization of inhibitors, imbibitions and enzyme activation. All the processes that occur before germination are activated by priming and persist following the re-desiccation of the seeds. Several workers also reported improvement in seed quality parameters a result of seed priming in various crops (8, 12).

Conclusion

The current study supports the theory that treating seeds with salicylic acid can be a viable method for reducing the effects of heat stress in wheat that is planted late. This concept has considerable potential for use beyond experimental verification, particularly in industrial and field settings, as it presents a cost-efficient and eco-friendly approach to boosting crop resilience and productivity in areas prone to heat. Integrating hormonal priming into regular seed management practices can help align wheat production systems with anticipated climate challenges, possibly enhancing food security and economic stability. These findings provide a generalized framework for advancing heat stress management strategies in cereals and suggest strong prospects for adoption in commercial agriculture.

Acknowledgements

The authors are thankful to Junagadh Agricultural University, College of Agriculture, for providing the necessary infrastructure and resources.

Authors' contributions

JRS was involved in the research activities and field establishment and writing of the research article. JBP and JRS corrected and proofread the research article. DVS and CAB were involved in statistical analysis work of the data collected during the research and participated in the sequence alignment. All authors read and approved of the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors declare that there is no conflict of interest

Ethical issues: None

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Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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