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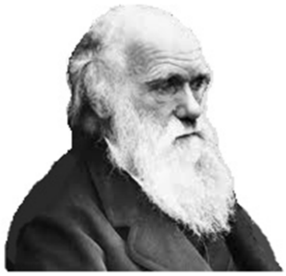

World News of Natural Sciences

An International Scientific Journal

WNOFNS 59 (2025) 267-293 EISSN 2543-5426

Investigating the Interactive Effects of Gibberellic Acid and Water Regimes on Wheat (*Triticum aestivum* L.) Grain Yield

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ABSTRACT

Wheat is a crucial crop in Pakistan, with production increasing due to improved practices. However, water scarcity and climate change pose significant threats. It highlights the importance of sustainable agricultural practices, including efficient water management, climate-resilient varieties, and integrated crop management. It also explores the potential of plant growth regulators like gibberellic acid in mitigating the negative impacts of stress factors on wheat yield. A field experiment was conducted in Faisalabad, Pakistan, to assess the impact of gibberellic acid (GA_3) on wheat yield under varying water regimes. An RCBD split design with three replications was used. Treatments included three GA_3 levels (0, 100, and 200 mg L^{-1}) and three water regimes: control, skip irrigation at booting, and skip irrigation at grain filling. Wheat cultivar Akbar-2019 was sown in November 2023. This study investigated the interactive effects of gibberellic acid (GA_3) and water regimes on wheat (*Triticum aestivum* L.) grain yield. A field experiment was conducted using a randomized complete block design with three replications. Treatments included three levels of GA_3 (0, 100, and 200 mg L^{-1}) and three water regimes: control (four irrigations), skip irrigation at the booting stage, and skip irrigation at the grain formation stage. Results showed significant main effects of GA_3 and water regimes on plant height, spike length, 1000-grain weight, grain protein content, harvest index, and inter-nodal length. The highest values for most parameters were observed in the treatment with 200 mg L^{-1} GA_3 and skip irrigation at the grain formation stage. The interaction between GA_3 and water regimes was significant for grain protein content and harvest index. Overall, the findings suggest that GA_3 application, particularly at 200 mg L^{-1}, can partially mitigate the negative impacts of water stress on wheat yield components. However,

(Received 06 January 2025; Accepted 02 February 2025; Date of Publication 04 February 2025)

the optimal combination of GA_3 and water regime may vary depending on specific environmental conditions and cultivar characteristics. Further research is needed to optimize GA_3 application rates and timing for different water stress scenarios.

***Keywords*:** Gibberellic Acid (GA3), Wheat Yield, Drought Stress, Irrigation Regimes, Triticum aestivum, Agronomic Practices

1. INTRODUCTION

Wheat is a cornerstone of Pakistan's agricultural landscape, playing a vital role in food security and the economy. It is the most important crop in the country, accounting for a significant portion of the daily caloric intake of the population. For the marketing year 2024-2025, wheat production in Pakistan is anticipated to reach 31.4 million metric tons (MMT), marking an 11% increase from the previous year's output of 28.2 MMT. This growth is attributed to expanded cultivation areas and enhanced yields due to favorable growing conditions and increased use of certified seeds. The adoption of efficient fertilizer usage and greater reliance on certified seeds have contributed positively to yield improvements, enabling farmers to achieve better outputs. The Pakistani government actively intervenes in the wheat market through minimum support prices and procurement policies, ensuring price stability and encouraging farmers to maintain production levels. Approximately 25% of total wheat production is procured by the government, which helps stabilize the market (Miller Refereed Magazine; 2024).

The government has set a wheat production target of 33.58 MMT for the Rabi season 2024-2025, aiming to cultivate wheat across approximately 10.368 million hectares (Business Recorder; 2024). However, provincial governments have proposed lower production estimates due to reduced sowing areas, projecting around 27.92 MMT (Arab News; 2024). Wheat consumption in Pakistan is projected to reach a record 30.9 MMT in 2024-25, reflecting a 2.3% increase from the previous year. This rising demand underscores the importance of maintaining robust domestic production levels. Enhanced availability of irrigation water has played a critical role in supporting wheat production despite challenges posed by irregular rainfall patterns. Sufficient irrigation mitigated the impact of minimal rainfall during key growing months (Milling MEA; 2024). Wheat accounts for 1.7 percent of GDP and 9.7 percent of agricultural value added.

The use of high-yielding cultivars, the availability of high-quality seed, more fertilizer, and improved weed management have all contributed to the rise in wheat productivity during the last three decades. Pakistan produced 25.50 million tons of wheat from 8.97 million hectares during the 2017-2018 wheat season, with an average productivity of 2.84 t/ha. The genetic yield potential of improved semi-dwarf wheat cultivars in Pakistan, when irrigated, is 8.0 t/ha. In irrigated areas, progressive wheat producers are achieving grain yields of 5-7 tons per hectare. Rainfed wheat yields around 1.2 tons per hectare, whereas irrigated wheat yields about 3.0 tons per hectare on average nationwide. (PARC, Wheat Program; 2020).

Water scarcity is one of the most serious threats that has emerged in many regions of the world, specifically in climate-change-affected countries (Varga *et al*., 2015).

The need for integrated strategies to address climate change impacts on wheat and rice production. It discusses agronomic practices like efficient water management, genetic approaches like disease resistance breeding, and phenomics using high-throughput technologies. This study emphasis the importance of interdisciplinary research to achieve sustainable agriculture in the face of climate change (Pérez-Méndez et al., 2021). In Pakistan, wheat crop is cultivated under different climatic and soil conditions. In some areas, production depends on rainfall where rainfall water is not enough to give higher production. We can see how primary resources such as water, air and the environment are gradually deteriorating as a result of the unnecessary use of agricultural. inorganic chemicals to boost productivity in the context of crop intensification On the other hand, natural resource sustainability should be avoided in order to feed the world's predicted rising population, which is predicted to reach 8.60 billion by 2030 by achieving extraordinary yield and satisfactory environmental modifications (Mendez & Popkin, 2004; Sharma et al., 2018).

This study developed an index to assess agricultural water scarcity considering both blue (surface/groundwater) and green (rainfall) water. Results show that 39% of global croplands faced water scarcity in the baseline period (1981-2005), and this is projected to increase under future climate scenarios. Decreased water availability is the primary driver of increased scarcity, while changes in green water availability significantly impact scarcity in arid/semiarid regions. This integrated approach provides valuable insights for developing effective water management strategies in a changing climate (Liu et al., 2022).

The multifaceted impacts of climate change on wheat production, including temperature changes, altered precipitation patterns, rising CO_2 levels, and sea-level rise. It examines the effects on growth, yield, and quality, while emphasizing the importance of selecting climate-resilient varieties and adapting agricultural practices (Yanagi, 2024). A review highlights the need for climate-smart farming systems to address crop diseases while minimizing environmental impact.

It emphasizes Integrated Crop Management (ICM) strategies, such as crop resistance, intercropping, and canopy manipulation, as alternatives to synthetic inputs. These strategies can reduce disease incidence, GHG emissions, and environmental impact, while enhancing food security. Further research is crucial to optimize the deployment of these ICM strategies across diverse cropping systems (Richard et al., 2022).

In winter wheat found that splitting N fertilizer applications (50% at sowing, 50% during jointing-booting) under drip irrigation with irrigation scheduling at 45 mm (I45N50-50) yielded the highest grain yield (9.83 t ha^{-1}) and biomass (19.91 t ha^{-1}). This approach was comparable to slow-release fertilizer (SRF100) in terms of yield and photosynthetic parameters. The I45N50-50 treatment offers a cost-effective and environmentally friendly alternative to SRF for winter wheat fertilization (Hamani et al., 2023b). Irrigation significantly increased wheat yield, with two irrigations yielding 79% more than dryland conditions. Sardari variety showed lower yield compared to Sirvan.

Bio-fertilizer consortia, particularly Mycorrhiza + Nitrozist and Phosphozist + Seaweed extract, significantly boosted wheat growth and yield in both varieties, with average yields reaching 5226.25 kg/ha and 4923.33 kg/ha in the two years (Vafa et al., 2024). These findings demonstrate the potential of integrated approaches involving irrigation and bio-fertilizers to enhance wheat productivity and mitigate the impacts of climate change. In the North China Plain; it is investigated that optimal irrigation and nitrogen (N) management for drip-irrigated winter wheat.

Results showed that split N application (50% at sowing, 50% during jointing-booting) with irrigation at 45 mm (I45N50-50) yielded the highest grain yield (9.72-9.94 t ha^{-1}) and significantly improved water use efficiency (2.61 kg/m^3) and N use efficiency. This strategy was deemed most effective by TOPSIS analysis, offering a sustainable and efficient approach for winter wheat production in the region (Hamani et al., 2023a).

A study in Bangladesh found that drought significantly reduced wheat yield. Foliar application of potassium (K_2SO_4) under drought stress improved biological yield of Kanchan (22.04%) and BARI Gom-30 (15.16%) compared to GA_3. Grain yield also increased with K_2SO_4 (Kanchan: 3.19%, BARI Gom-30: 2.59%) and GA_3 (Kanchan: 1.47%, BARI Gom-30: 1.18%) under drought. These results suggest that foliar potassium application can be a valuable strategy to mitigate drought stress in wheat (Haque et al., 2022).

Wheat plants subjected to heat stress showed improved growth (height, weight) and photosynthesis when treated with a combination of sodium nitroprusside (SNP) and gibberellic acid (GA_3). This combined treatment significantly enhanced antioxidant enzyme activity and reduced oxidative damage compared to individual applications or no treatment. These findings suggest that SNP and GA_3 synergistically mitigate heat stress in wheat (Zhang et al., 2023).

Two experiments on wheat showed that PGRs like GA_3 and CCC (cytokinin and cycocel) can improve germination (Homa cultivar) and mitigate drought stress. Drought reduced soluble protein, while PGRs increased antioxidants (SOD, PPO), osmolytes (proline, glycine betaine), and reduced oxidative damage (MDA) in hydroponically grown plants.

These findings suggest PGRs as potential tools to enhance wheat tolerance to drought (Sadeghi et al., 2023). A study investigated the effect of GA_3 on wheat varieties with varying vernalization needs. While GA_3 did not alter the vernalization requirement for flowering, it influenced the transition from vegetative to generative stages in some varieties. Photosynthetic activity was monitored, but no significant impact of GA_3 on photosynthesis was observed in the spring and one winter variety (Skalicky et al., 2020).

2. MATERIAL AND METHODS

2. 1. Experimental site and design

A field experiment was conducted at Agronomic Research Area, University of Agriculture Faisalabad, during winter season 2023 to evaluate the effect of exogenous application of gibberellic acid on yield of wheat (*Triticum aestivum* L.) under different water regimes. Under the split plot arrangement, the Randomized complete block design (RCBD) was replicated three times, by maintaining a net plot size of 7.5 m × 1.8 m. Overall 27 plots were prepared and succeeded in a way that easily distinguished the replications and plots as well as treatments.

Wheat cultivar (Akbar-2019) was sown in lines using the flat sowing method during the last week of November 2023. Treatment combinations will include three levels of gibberellic acid application (0 mg L^{-1}, 100 mg L^{-1} and 200 mg L^{-1}) with different water regimes (control, skip irrigation at booting stage and skip irrigation at grain formation stage).

2. 2. Soil analysis

Prior to fertilizer application, soil samples from the experimental site were taken using a soil auger to a depth of 0-30 cm before sowing. After air drying, collected samples were combined and crushed to pass through a 2 mm filter for physio-chemical analysis (Table 1).

Table 1. Physio-chemical properties of soil.

Sr. No.	Physio-chemical properties	Units	Analysis Value
1	EC	dsm^{-1}	1.32
2	Soil pH	-	7.1
3	Organic Matter	%	0.99
4	Available P	Ppm	7.6
5	Available K	Ppm	161
6	Available N	%	0.047
7	Saturation	%	44
8	Texture	-	Loamy
9	SAR	-	8
10	ESP	-	7

2. 3. Crop husbandry

On November 18, 2023, the wheat crop was planted at a seed rate of 125 kg ha^{-1}. For the current study, the wheat variety Akbar-2019 was chosen as the experimental material. Ayub Agricultural Research Institution (AARI) Faisalabad provided the seeds. The study used a Randomized complete block design (RCBD) with three replications in a split-plot layout.

The plot's real dimensions were 7.5 m and 1.8 m. The NPK fertilizer was applied at a rate of 115-88-63 NPK kg ha^{-1} with urea and di-ammonium phosphate serving as distinct sources of N, P and K. When preparing the field, as well as the seedbed of the soil, the entire volume of P and N were used. The remaining nitrogen was split into two parts and used in the first and second irrigations, respectively. In the recommended irrigation treatment, a total of four irrigations were performed. At the booting stage after 80 days of plating and the grain filling stage after 110 days of sowing, the crop was given two skip irrigations. Unwanted plants were removed from the crop, saving it. Physical maturity was ached in April 2024 and the crop was harvested. To manage wheat weeds, a post- emergence herbicide called "Council (Ethoxysulfuron + tramine)" was used at a dosage of 75g per acre of the area on the same day of sowing. At two separate stages of the crop, 20 and 40 days after seeding by hand hoeing, two weeding were done to limit the influence of word infestation. Sowing method were line sowing.

2. 4. Seed bed preparation

The field was flood irrigated prior to ploughing; the practice is commonly known as Rouni irrigation. Field was ploughed two times with cultivator for providing favorable conditions for seed germination when field moisture was at field capacity level.

2. 5. Harvesting and Threshing

Crop was harvested on 15 of April 2024. Crop was harvested manually when it reached maturity. At maturity, spike color was turned golden from green. After manual harvesting crop was sun dried for 7 days to reduce the moisture level in grains as higher grain moisture results in grain breaking during threshing. After sun drying, wheat from each plot, was threshed using wheat thresher at Agronomy Farm.

2. 6. Weather data

Weather data for growing season is presented below. Data for weather showed the actual value for mean temperature, rainfall, humidity, evaporation, and wind speed thorough out the growing season from sowing to harvesting of crop. Weather factors influence crop productivity positively or negatively.

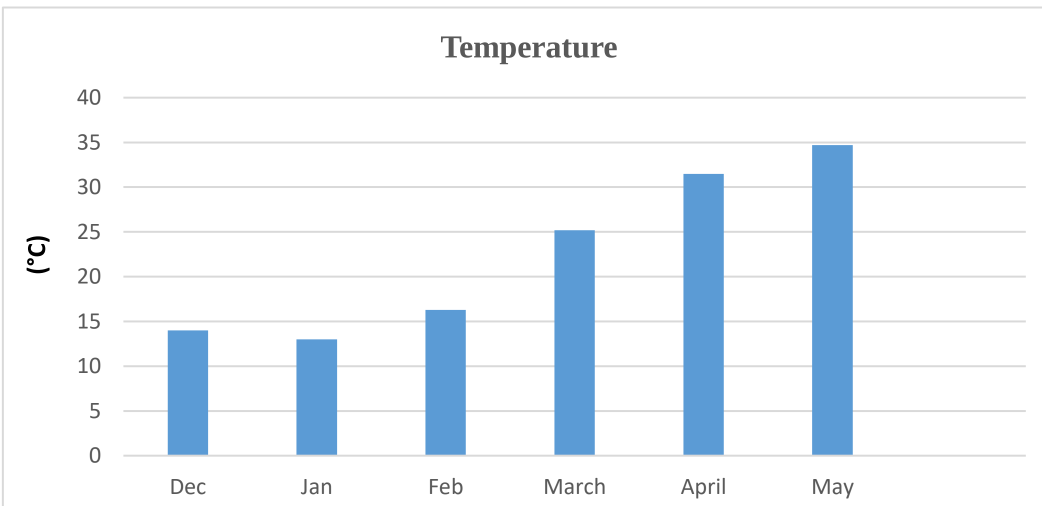

Figure 1. Mean monthly temperature °C during growing season 2023-2024.

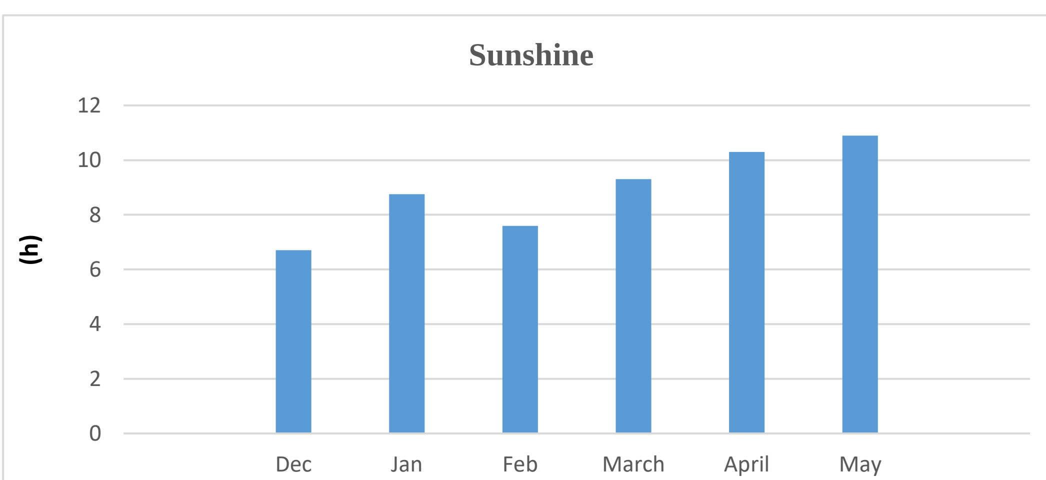

Figure 2. Mean monthly sunshine hours (h) during growing season 2023-2024.

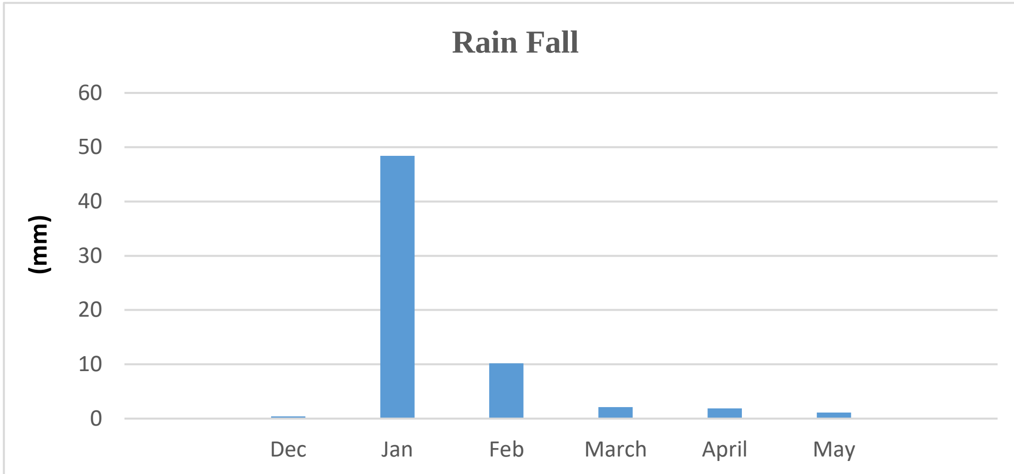

Figure 3. Mean monthly rainfall (mm) during growing season 2023-2024.

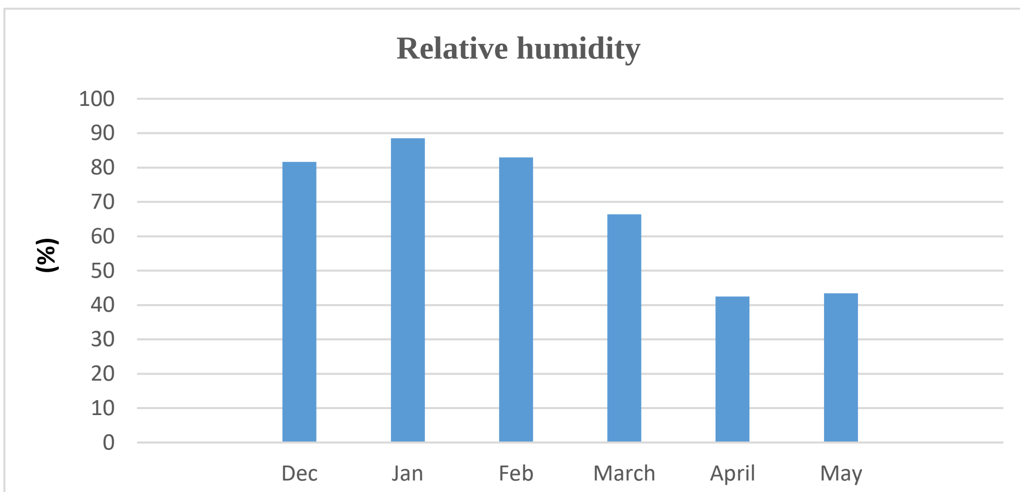

Figure 4. Mean monthly relative humidity (%) during growing season 2023-2024.

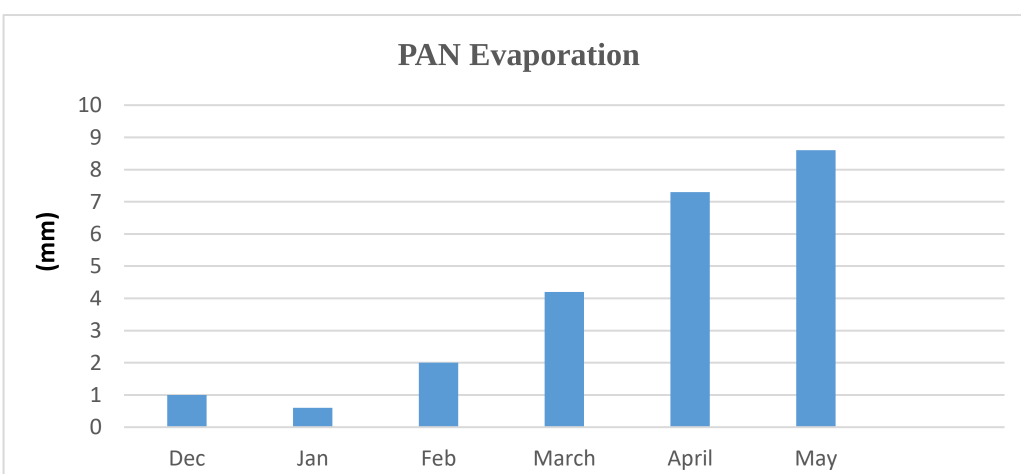

Figure 5. Mean monthly evaporation (mm) during growing season 2023-2024.

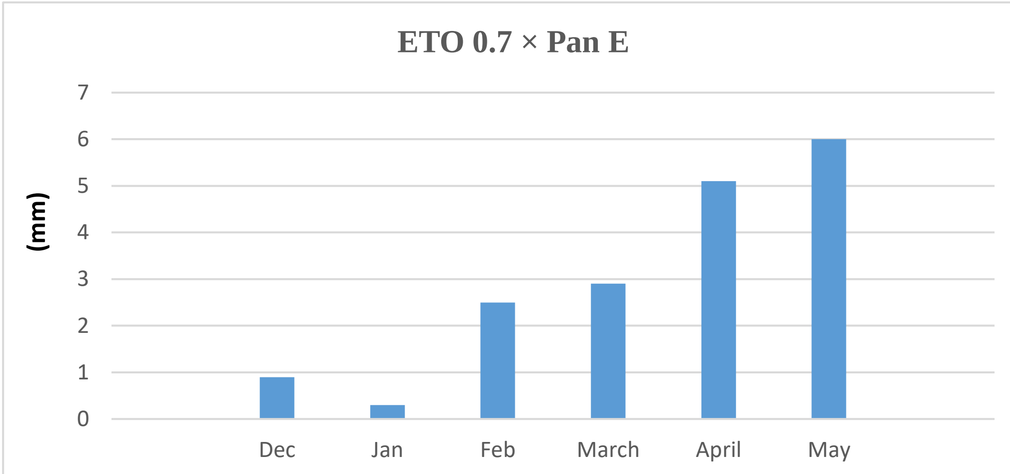

Figure 6. Mean monthly Evapo-transpiration (mm) during growing season of 2023-2024.

3. RESULTS AND DISCUSSION

The experiment on the "interactive effects of gibberellic acid and water regimes on wheat (*Tritium aestivum* L.) grain yield", was conducted at the Agronomic research area, University of Agriculture, Faisalabad. The experiment was conducted during rabi season 2023-2024.

The data on various parameters like growth, yield and yield components were collected during crop period and analyzed by standard procedure.

3. 1. Plant Height

Plant height is a very important morphological character which shows the growth of the plant and indirect determinant of the yield. It can be varying in different varieties of wheat crop; soil nutrients status and stresses faces by the plant during their life cycle. Water treatment and gibberellic acid levels have significant ($P < 0.05$) effect on the plant height (Table 2b).

Maximum plant height of W2 skip irrigation at grain formation stage (113.03 cm) was recorded with a gibberellic acid application of 200 mg/L. While the minimum plant height (106.87 cm) was reported in therapy W0 Control (4 Irrigation, where 100 mg/L of Gibberellic acid) was applied.

Analysis of variance presented in Table 2a, revealed that plant height under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found non-significant. Statistical analysis showed that statistically maximum plant height (111.67 cm) was attained with W2 (skip irrigation at grain formation stage) whereas minimum plant height (108.00 cm) was attained with W0, (control). Statistical analysis showed that maximum plant height (113.03 cm) was attained with G2 (200 mg/L) whereas minimum (108.76 cm) with G0 (control).

The conclusion of this trail is aligned with Iqbal and Ashraf (2013) who stated after their finding that the plant height increased as the level of gibberellic acid rises. Ashraf et al. (2002) also concluded that the plant height increased as the gibberellic acid levels goes on increasing. The possible reason for the higher plant is that the vegetative development of crops is enhanced by nitrogen. GA_3 (200 ppm) boosted wheat growth (height, leaf area, yield) under normal conditions. Under drought, GA_3 improved plant health (enzymes, protein) while ABA stunted growth. These findings highlight the contrasting effects of these plant hormones on wheat performance under varying water availability (Lamlom et al., 2025).

Tables 2. Effect of Gibberellic acid on plant height of wheat under various water regimes.

a) Analysis of Variance Table

Source	DF	SS	MS	F
R	2	60.81	30.4052	
W	2	61.378	30.689	5.29 ^{ns}
Error R*W	4	23.216	5.8039	
G	2	27.75	13.875	4 ^{ns}
W*G	4	8.495	2.1237	0.61^{ns}
Error R*W*G	12	41.592	3.466	
Total	26	223.241		
Grand Mean	109.69			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	106.87 d	108.32 bcd	108.82 bcd	108.00 B
W1 = Skip Irrigation at booting stage	108.91bcd	107.88 cd	111.46 ab	109.41 AB
W2 = Skip Irrigation at grain formation stage	110.51 a-d	111.45 abc	113.03 a	111.67 A
Mean (G)	108.76 B	109.22 AB	111.10 A	

3. 2. Spike Length (cm)

Water treatment and gibberellic acid levels have significant ($P < 0.05$) effect on the plant height (Table 3b). Maximum spike length of treatment W2 skip irrigation at grain formation stage (13.400 cm) was recorded with a gibberellic acid application of 200 mg/L. While the minimum spike length (11.147 cm) was reported in therapy at Control (4 Irrigation) (W0), where 100 mg/L of Gibberellic acid was applied.

Analysis of variance presented in Table 3 revealed that Spike Length under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found non-significant. Statistical analysis showed that statistically maximum Spike Length (13.073 cm) was attained with W2 (skip irrigation at grain formation stage) whereas minimum spike length (11.823 cm) was attained with W0, (control). Statistical analysis showed that maximum spike length (12.951 cm) was attained with G2 (200 mg/L) whereas minimum (12.040 cm) with G0 (control).

These findings were supported by (Rebetzke & Richards, 2000). This conclusion was also consistent with the findings of (Pavlista et al., 2014), who discovered that gibberellic acid had growth-promoting effects on spike length.

Tables 3. Effect of Gibberellic acid on spike length of wheat under various water regimes.

a) Analysis of variance

Source	DF	SS	MS	F
R	2	12.2154	6.10771	
W	2	7.6467	3.82337	20.55*
Error R*W	4	0.7444	0.18609	
G	2	3.9273	1.96366	4.44^{ns}
W*G	4	0.4085	0.10212	0.23^{ns}
Error R*W*G	12	5.3088	0.4424	
Total	26	30.2511		
Grand Mean	12.555			

b) Comparison of mean Treatment

Irrigation Regimes	**Gibberellic Acid**			**Mean (W)**
	G0 = 0 mg L^{-1}	**G1 = 100 mg L^{-1}**	**G2 = 200 mg L^{-1}**	
W0 = Control (4 Irrigation)	11.147 c	11.957 bc	12.367 ab	11.823 B
W1 = Skip Irrigation at booting stage	12.463 ab	12.757 ab	13.087 a	12.769 A
W2 = Skip Irrigation at grain formation stage	12.510 ab	13.310 a	13.400 a	13.073 A
Mean	12.040 B	12.674	12.951	

3. 3. 1000-Grain Weight (g)

The weight of 1000 seeds are an essential component in yielding characteristics. If the crop weighs more than 1000 grains, the crop yield will be improved. Analysis of that same variance showed (Table 4a) that varietals and nitrogen did not significantly alter the crop's 1000-Grain Weight. Table 4b, data showed that the maximum weight of 1000 grains of W2 skip irrigation at grain formation stage (42.047 g) was recorded with a gibberellic acid application of 200 mg/L. While the minimum weight of 1000 grains (37.877 g) were reported in therapy W0 Control (4 Irrigation), where 100 mg/L of Gibberellic acid was applied.

Analysis of variance presented in table revealed that 1000-Grain Weight under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found non-significant. Statistical analysis showed that statistically maximum 1000-Grain Weight (40.622 g) was attained with W2 (skip irrigation at grain formation stage) whereas minimum 1000-Grain Weight (38.429 g) was attained with W_0, (control). Statistical analysis showed that maximum 1000-Grain Weight (40.228 g) was attained with G2 (200 mg/L) whereas minimum (38.418 g) with G0 (control).

These results are in accordance with Shaddad et al. (2013), who noticed that the application of gibberellic acid massively increased the 1000 grain weight during seed and stem elongation. These results are consistent with the Al Mahmud et al. (2019), which demonstrated an interaction non-important effect on cultivars and gibberellic acid.

Tables 4. Effect of Gibberellic acid on 1000 grain weight of wheat under various water regimes

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	42.034	21.017	
W	2	26.46	13.2302	7.67*
Error R*W	4	6.899	1.7247	
G	2	15.237	7.6187	8.93**
W*G	4	1.837	0.4593	0.54^{ns}
Error R*W*G	12	10.237	0.8531	
Total	26	102.705		
Grand Mean	39.227			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	37.877 c	38.260 c	39.150 bc	38.429 B
W1 = Skip Irrigation at booting stage	38.030 c	38.373 bc	39.487 bc	38.630 B
W2 = Skip Irrigation at grain formation stage	39.347 bc	40.473 ab	42.047 a	40.622 A
Mean	38.418 B	39.036 B	40.228	

3. 4. Grain protein Content

Water treatment and gibberellic acid levels have significant ($P < 0.05$) effect on the plant height (Table 5b). Maximum grain protein content of W2 skip irrigation at grain formation stage (13.340 %) was recorded with a gibberellic acid application of 200 mg/L. While the minimum grain protein content (11.063 %) was reported in therapy W0 Control (4 Irrigation), where 100 mg/L of Gibberellic acid was applied.

Analysis of variance presented in table revealed that Grain protein Content under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found significant. Statistical analysis showed that statistically maximum Grain protein Content (13.021) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Grain protein Content (11.891) was attained with W0, (control). Statistical analysis showed that maximum Grain protein Content (12.941) was attained with G2 (200 mg/L) whereas minimum (11.681) with G0 (control). The result was supported by the findings of Al Mahmud et al. (2019) who investigated that vermicompost application caused improvements in protein and NPK contents both in soil and plant.

Tables 5. Effect of Gibberellic acid on grain protein content of wheat under various water regimes

a) Analysis of variance

Source	DF	SS	MS	F
R	2	13.1407	6.57036	
W	2	6.8017	3.40083	6.67*
Error R*W	4	2.0405	0.51011	
G	2	7.1457	3.57283	15.81**
W*G	4	0.9761	1.4401	6.38*
Error R*W*G	12	2.7121	0.22601	
Total	26	32.8166		
Grand Mean	12.316			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	11.063 d	12.020 bc	12.590 ab	11.891 B
W1 = Skip Irrigation at booting stage	11.287 cd	11.930 bcd	12.893 ab	12.037 B

W2 = Skip Irrigation at grain formation stage	12.693 ab	13.030 ab	13.340 a	13.021 A
Mean	11.681 C	12.327 B	12.941 A	

3. 5. Harvest Index (%)

The harvest index represents the percentage of crop yield to crude fiber. The effectiveness of cultivars to transmit the assimilates to economic parts of the crop was demonstrated by the Harvest Index. Variance analysis showed that the harvest index (HI) was considerably affected by cultivars.

The greatest harvest index (39.743 %) data shown in the Table 6b in the treatment W2 skip irrigation at grain formation stage applied 200 mg/L containing gibberellic acid. While the minimal harvest index (36.270 %) was obtained when gibberellic acid was not administered in treatment W0 Control (4 Irrigation).

Analysis of variance presented in table revealed that Harvest Index under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found highly significant. Statistical analysis showed that statistically maximum Harvest Index (38.407 %) was attained with W_2 (skip irrigation at grain formation stage) whereas minimum Harvest Index (37.206 %) was attained with W0, (control). Statistical analysis showed that maximum Harvest Index (38.573 %) was attained with G2 (200 mg/L) whereas minimum (36.707 %) with G0 (control).

These findings are consistent with Peng et al. (2014), which helps to improve harvests by increasing the dose of gibberellic acid. Aldesuquy and Ibrahim (2001) also showed a 20 per cent fall in the wheat yield index by decreasing the gibberellic acid delivery from 150 mg/L and 50 mg/L.

Tables 6. Effect of Gibberellic acid on harvest index of wheat under various water regimes.

a) Analysis of variance

Source	DF	SS	MS	F
R	2	12.6315	6.31574	
W	2	10.0545	5.02727	3.29*
Error R*W	4	6.1157	1.52893	
G	2	16.1246	8.06231	7.25*
W*G	4	2.3919	9.7425	8.76**
Error R*W*G	12	13.346	1.11216	
Total	26	60.6642		
Grand Mean	37.549			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	36.270 b	37.540 ab	37.807 ab	37.206 A
W1 = Skip Irrigation at booting stage	36.437 b	36.500 b	38.170 ab	37.036 A
W2 = Skip Irrigation at grain formation stage	37.413 b	38.063 ab	39.743 a	38.407 A
Mean	36.707 B	37.368 B	38.573 A	

3. 6. Inter Nodal length (cm)

Water treatment and gibberellic acid levels have significant ($P < 0.05$) effect on the plant height (Table 7b). Maximums inter nodal length of treatment W2 skip irrigation at grain formation stage (20.143 cm) was recorded with a gibberellic acid application of 200 mg/L. While the minimum inter nodal length (18.800 cm) was reported in therapy W0 Control (4 Irrigation), where 100 mg/L of Gibberellic acid was applied.

Analysis of variance presented in table revealed that Inter Nodal length under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found highly significant. Statistical analysis showed that statistically maximum Inter Nodal length (19.920) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Inter Nodal length (19.34) was attained with W0, (control). Statistical analysis showed that Inter Nodal length Index (19.822) was attained with G2 (200 mg/L) whereas minimum (18.498) with G0 (control).

These results resemble the findings of Iqbal and Ashraf (2013) who observed the enhanced nodal length by applying gibberellic acid to the various plants. It is evaluated that the effects of GA-sensitive Rht13 genes on wheat yield and drought tolerance. By crossing lines with different Rht genes, researchers observed reduced plant height, increased spike length, and improved grain yield in F1 hybrids under drought stress. Expression analysis confirmed the role of Rht13 in these traits. These findings suggest the potential of GA-sensitive Rht genes for developing high-yielding and drought-tolerant wheat varieties (Khalid et al., 2023).

Tables 7. Effect of Gibberellic acid on Inter nodal length of wheat under various water regimes.

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	5.0668	2.5334	
W	2	2.4493	1.22464	7.46*
Error R*W	4	0.6569	0.16424	

G	2	0.4795	0.23975	2.01*
W*G	4	0.1284	1.2516	10.32**
Error R*W*G	12	1.4304	0.1192	
Total	26	10.2113		
Grand Mean	19.67			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	18.800 ab	19.830 ab	19.903 ab	19.34 AB
W1 = Skip Irrigation at booting stage	19.003 c	19.317 bc	19.420 abc	19.14 B
W2 = Skip Irrigation at grain formation stage	19.690 abc	19.927 ab	20.143 a	19.920 A
Mean	18.498 B	19.691 AB	19.822 A	

3. 7. Stem Diameter (mm)

Water treatment and gibberellic acid levels have significant ($P < 0.05$) effect on the plant height (Table 8b). Maximum stem diameter of treatment W2 skip irrigation at grain formation stage (4.79 mm) was recorded with a gibberellic acid application of 200 mg/L. While the minimum stem diameter (3.91 mm) was reported in therapy W0 Control (4 Irrigation), where 100 mg/L of gibberellic acid was applied.

Tables 8. Effect of Gibberellic acid on stem diameter of wheat under various water regimes.

a) Analysis of variance

Source	DF	SS	MS
R	2	1.02912	0.51456
W	2	0.60765	0.30383^{ns}
Error R*W	4	0.66204	0.16551
G	2	0.59574	0.29787*
W*G	4	0.07335	0.3423*
Error R*W*G	12	0.77224	0.06435

Total	26	3.74014	
Grand Mean	4.4585		

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	3.91 b	4.1 ab	4.49 ab	4.16 A
W1 = Skip Irrigation at booting stage	4.03 b	4.27 ab	4.69 a	4.39 A
W2 = Skip Irrigation at grain formation stage	4.65 ab	4.67 ab	4.79 a	4.6667 A
Mean	4.3122 B	4.4011 B	4.6622 A	

Analysis of variance presented in table revealed that Stem Diameter under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found significant. Statistical analysis showed that statistically maximum Stem Diameter (4.6667) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Stem Diameter (4.16) was attained with W0, (control). Statistical analysis showed that maximum Stem Diameter (4.6622) was attained with G2 (200 mg/L) whereas minimum (4.3122) with G0 (control).

These results resemble the findings of Aldesuquy and Ibrahim (2001) who observed the enhanced stem diameter by applying gibberellic acid to the various plants. The results were also similar to Allan et al. (1959) who noted that when gibberellic acid was added to soil, it infiltrates the roots, supplying nutrients to the roots that are utilized by rhizosphere plants and bacteria as well as increased plant growth (Bush, 1996).

3. 8. Number of Tillers (m^{-2})

Productive tillers of wheat crop are significantly ($P<0.05$) influenced by both cultivars and nitrogen levels as depicted in Table 9b. The highest number of productive tillers (347.35 m^{-2}) was counted in treatment W2 skip irrigation at grain formation stage where 200 mg/L gibberellic acid was applied. While minimum number of productive tillers (326.57 m^{-2}) recorded in treatment W0 Control (4 Irrigation) in which no gibberellic acid was applied.

Analysis of variance presented in table revealed that Number of Tillers under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found non-significant. Statistical analysis showed that statistically maximum Number of Tillers (336.64) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Number of Tillers (330.38) was attained with W0, (control). Statistical analysis showed that maximum Number of Tillers (341.67) was attained with G2 (200 mg/L) whereas minimum (323.67) with G0 (control).

Increasing the level of gibberellic acid proved beneficial in boosting the number of productive tillers. Because by enhancing the gibberellic acid level the rate of mortality of tiller reduced and because of this more tiller are produced from the main stem. This result is matched with the finding of (Pavlista et al., 2014). The likely reason for larger number of tillers were responsible for the increase overall gibberellic acid availability notably during tillering due acknowledgment to which microbial apparatus and strong plant growth which consequently enhanced the number of love the quality (Shaddad et al., 2013).

Tables 9. Effect of Gibberellic acid on number of tillers/m^2 of wheat under various water regimes

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	551.26	275.632	
W	2	151.19	75.597	1.1*
Error R*W	4	276	69.001	
G	2	1581	790.502	5.76*
W*G	4	298.81	74.703	0.54^{ns}
Error R*W*G	12	1645.94	137.162	
Total	26	4504.22		
Grand Mean	334.18			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	326.57 bc	331.69 abc	334.69 abc	330.38 B
W1 = Skip Irrigation at booting stage	323.53 bc	338.26 abc	342.98 ab	334.92 A
W2 = Skip Irrigation at grain formation stage	320.91 c	341.65 abc	347.35 a	336.64 A
Mean	323.67 B	337.20 A	341.67 A	

3. 9. Number of grains

Among the most important parameters indicating the productivity of wheat crop is grains per spike. The availability of sufficient crop inputs (nutrient and water demand), while maintaining proper crop husbandry, increases the number of grain yield per plant. Results presented in Table 10b amply proven that the quantity of grains per spike was considerably altered in all treatments. Comparison of single therapy indicated a record of 200 mg/L gibberellic acid for the largest grain yield per plant per shock (58 grains) in therapy W2 skip irrigation at grain formation stage. At least the number of grains registered (53 grains) in treatment W0 Control (4 Irrigation) where zero mg/L gibberellic acid was applied.

Analysis of variance presented in table revealed that Number of grains under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found significant. Statistical analysis showed that statistically maximum Number of grains (56.889) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Number of grains (54.55) was attained with W0, (control). Statistical analysis showed that Number of grains (56.778) was attained with G2 (200 mg/L) whereas minimum (53.00) with G0 (control). Ashraf et al. (2002) observed that gibberellic acid greatly boosted the rate of application per spike in linear terms. The grains per point play a major role in the production of grain. Iqbal and Ashraf (2013) observed a substantial effect of gibberellic acid on kernels per spike and decreased kernels by 50 and 100 kg ha^{-1} to 8% per spike, and 5% compared with N, respectively, by 150 kg/ha. This is attributable to a 15 percent drop in flora in gibberellic acid between 150 and 50 kg/ha.

Tables 10. Effect of Gibberellic acid on plan height of wheat under various water regimes

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	33.185	16.5926	
W	2	55.63	27.8148	5.71*
Error R*W	4	19.481	4.8704	
G	2	64.519	32.2593	12.1**
W*G	4	14.148	8.587	3.22*
Error R*W*G	12	32	2.6667	
Total	26	218.963		
Grand Mean	54.963			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	53 cde	55 a-d	55.67 a-d	54.55 AB
W1 = Skip Irrigation at booting stage	51 e	52.66 de	56.67 abc	53.44 B
W2 = Skip Irrigation at grain formation stage	55 bcd	57.67 ab	58 a	56.889 A
Mean	53.00 B	55.111 A	56.778	

3. 10. Number of Spikelet/spike

Water treatment and gibberellic acid levels have significant ($P < 0.05$) effect on the plant height (Table 11b). Maximum number of spikelet of treatment W2 skip irrigation at grain formation stage (18.223 sparklets) was recorded with a gibberellic acid application of 200 mg/L. While the minimum number of spikelet (15.000 spikelet) was reported in therapy W0 Control (4 Irrigation), where 100 mg/L of Gibberellic acid was applied.

Analysis of variance presented in table revealed that Number of Spikelet/spikes under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found highly non-significant. Statistical analysis showed that statistically maximum Number of Spikelet/spike (17.324) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Number of Spikelet/spike (16.556) was attained with W0, (control). Statistical analysis showed that maximum Number of Spikelet/spike (17.852) was attained with G2 (200 mg/L) whereas minimum (15.722) with G0 (control). Al Mahmud et al. (2019) found that nitrogen and foliar application gibberellic acid resulted in a significant increase number of spikelets as compared to chemical fertilizer application. This result closely relates to the findings of Shaddad et al. (2013) who used gibberellic acid to the plants.

Tables 11. Effect of Gibberellic acid on number of spikelets per spike of wheat under various water regimes.

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	6.3694	3.1847	
W	2	2.7583	1.3792	0.83*
Error R*W	4	6.6236	1.6559	
G	2	22.4772	11.2386	14.11**
W*G	4	1.8108	0.4527	0.57^{ns}
Error R*W*G	12	9.556	0.7963	
Total	26	49.5953		
Grand Mean	16.983			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	15.000 d	17.000 abc	17.667 abc	16.556 A
W1 = Skip Irrigation at booting stage	15.750 cd	17.787 ab	17.667 abc	17.068 A

W2 = Skip Irrigation at grain formation stage	16.417 bcd	17.333 abc	18.223 a	17.324 A
Mean	15.722 B	17.373 A	17.852	

3. 11. Grain Yield (kg ha^{-1})

Grain output in wheat and perhaps other cereal products is the most essential metric and the result of the number of driving and interrelated components. This includes number of productive tillers, grain yield per plant per spike and average weight of the grain. Changes in grain yield may be linked to changes in all those components. Variance table analysis (Table 12a) demonstrated that cultivars had an unimportant influence, whereas nitrogen had a considerable effect on gain. The mean results of treatments are depicted in Table 12b. In treatment W2 skip irrigation at grain formation stage when 200 mg/L gibberellic acid was used, the highest grain production (5.8200 kg ha^{-1}) was recorded. In the case of minimal (4.0733 kg ha^{-1}) grain yield obtained in treatment W0 Control (4 Irrigation) where gibberellic acid has not been administered.

Analysis of variance presented in table revealed that Grain Yield under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found significant. Statistical analysis showed that statistically maximum Grain Yield (5.259) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Grain Yield (4.677) was attained with W0, (control). Statistical analysis showed that maximum Grain Yield (5.3956) was attained with G2 (200 mg/L) whereas minimum (4.493) with G0 (control).

The results are consistent agreement Peng et al. (2014), who observed that had a major impact on grain production. In the plots where the gibberellic acid rate increased from 150 lb weight 100 & 50 kg ha^{-1} correspondingly, the mean grain yield decreased from 41 and 21 percent. These results agree with the findings from Mathur et al. (1992), where the use of supplemental gibberellic acid water with weight fraction of gibberellic acid increased, the result of which was an increase in the total number of tillers was that senescence of the leaves delayed, which initiated the photosynthetic activity after grain filling, was the most important cause of grain filling. The Worland and Petrovic (1988) also corroborated the results that tillering phases in wheat are particularly essential in terms of the grain production. Due to the availability of appropriate humidity in tillering and the use of additional gibberellic acid, the photosynthesis rate has increased.

Tables 12. Effect of Gibberellic acid on grain yield of wheat under various water regimes

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	1.49532	0.74766	
W	2	1.58279	0.79139	8.67*
Error R*W	4	0.3653	0.09133	

G	2	3.66765	1.83383	16.57**
W*G	4	0.57144	0.14286	1.29*
Error R*W*G	12	1.32818	0.11068	
Total	26	9.01067		
Grand Mean	4.9352			

b) Comparison of mean Treatment

Irrigation Regimes	**Gibberellic Acid**			**Mean (W)**
	G0 = 0 mg L^{-1}	**G1 = 100 mg L^{-1}**	**G2 = 200 mg L^{-1}**	
W0 = Control (4 Irrigation)	4.073 d	4.8967 bc	5.0600 bc	4.677 B
W1 = Skip Irrigation at booting stage	4.6467 cd	4.6567 cd	5.3067 ab	4.870 AB
W2 = Skip Irrigation at grain formation stage	4.760 bc	5.1967 bc	5.8200 a	5.259 A
Mean	4.493 C	4.9167 B	5.3956 A	

3. 12. Biological yield

Biological production (kg ha^{-1}) is an important element because in complement to grain yields, farmers are worried about straw yield and play a crucial part in crop assessments. Table 13a shows clearly that all treatment has a significant impact on biological yield. Comparison of the treatments showed that in the treatment W2 skip irrigation at grain formation stage maximum biological yielding (11.26) was recorded, with a gibberellic acid application of 200 mg/L.

While the minimum biological output (9.747 kg ha^{-1}) was reported in therapy W0 Control (4 Irrigation), where 100 mg/L of Gibberellic acid was applied.

Analysis of variance presented in table revealed that biological yield under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found highly significant. Statistical analysis showed that statistically maximum Biological yield (10.701) was attained with W2 (skip irrigation at grain formation stage) whereas minimum Biological yield (10.253) was attained with W0, (control). Statistical analysis showed that maximum Biological yield (11.26) was attained with G2 (200 mg/L) whereas minimum (9.949) with G0 (control).

Therefore, the combined interaction of gibberellic acid and inorganic nutrients had positive impact on yield attributes of various crops including rice (Ashraf et al., 2002), wheat and barley (Pavlista et al., 2014). The result was supported by the findings of Shaddad et al. (2013) who investigated that gibberellic acid application caused improvements in NPK contents both in soil and plant

Tables 13. Effect of Gibberellic acid on biological yield of wheat under various water regimes.

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	6.6794	3.3397	
W	2	0.9096	0.45481	0.41*
Error R*W	4	4.4827	1.12068	
G	2	8.4968	4.2484	17.85**
W*G	4	0.311	0.7975	3.35**
Error R*W*G	12	2.8568	0.23806	
Total	26	23.7363		
Grand Mean	10.489			

b) Comparison of mean Treatment

Irrigation Regimes	Gibberellic Acid			Mean (W)
	G0 = 0 mg L^{-1}	G1 = 100 mg L^{-1}	G2 = 200 mg L^{-1}	
W0 = Control (4 Irrigation)	9.747 b	9.933 b	11.08 a	10.253 A
W1 = Skip Irrigation at booting stage	10.08 ab	10.36 ab	11.09 a	10.512 A
W2 = Skip Irrigation at grain formation stage	10.02 ab	10.473 ab	11.61 a	10.701 A
Mean	9.949 B	10.256 B	11.26 A	

3. 13. Stem water Soluble Carbohydrate (WSC)

Water soluble carbohydrates (WSC) are the primary fermentation substrate. In temperate grass forages, glucose, fructose, sucrose, and fructans are the primary WSC. New varieties of ryegrass have been developed in the United Kingdom to express high levels of WSC. Stem water-soluble carbohydrate in drought tolerant cultivars were observed to be higher than that in sensitive genotypes, both under control and stress conditions.

Analysis of variance presented in table revealed that stem water soluble carbohydrates under skip irrigations at different stages and different levels of gibberellic acid were affected significantly. While the interaction of irrigation regimes and gibberellic acid was found highly significant. Statistical analysis showed that the irrigation regimes does not statistically affect the stem water soluble carbohydrates, the maximum stem water soluble carbohydrates (1.5689) was attained with W0 (Control).

Statistical analysis showed that maximum stem water soluble carbohydrates (1.7878) was attained with G0 (0 mg/L) where as minimum (1.3378) with G2 (200 mg/L) (Li WeiYu et al., 2012). Studies on WSC QTL have been reported in rice, wheat, maize barley and perennial ryegrass. QTL studies using three wheat mapping populations showed that WSC accumulation was controlled by many genes, and plays an important role in assuring stable yield and grain size. With the rapid increases in number of molecular markers, association analysis has become an important tool for dissection of complex traits.

Tables 14. Effect of Gibberellic acid on stem water-soluble carbohydrate of wheat under various water regimes.

a) Analysis of Variance

Source	DF	SS	MS	F
R	2	0.05807	0.02903	
W	2	0.00996	0.00498	0.49*
Error R*W	4	0.04031	0.01008	
G	2	0.9186	0.4593	161.68**
W*G	4	0.01484	0.00371	1.31**
Error R*W*G	12	0.03409	0.00284	
Total	26	1.07587		
Grand Mean	1.5511			

b) Comparison of mean Treatment

Irrigation Regimes	**Gibberellic Acid**			**Mean (W)**
	G0 = 0 mg L^{-1}	**G1 = 100 mg L^{-1}**	**G2 = 200 mg L^{-1}**	
W0 = Control (4 Irrigation)	1.82	1.5633	1.3233	1.5689 A
W1 = Skip Irrigation at booting stage	1.74	1.4767	1.3567	1.5244 A
W2 = Skip Irrigation at grain formation stage	1.8033	1.5433	1.3333	1.5600 A
Mean	1.7878 A	1.5278 B	1.3378 C	

4. DISCUSSION

Wheat (*Triticum aestivum* L.) is a staple food and one of Pakistan's key agricultural crops. During the Rabi season of 2021-22, 80 percent of farmers in Pakistan would cultivate it over an area of 9 million hectares. Drought stress is a major problem, which reduces the wheat yield globally by effecting the growth drastically. A field experiment was conducted in the Agronomic Research Area, University of Agriculture, Faisalabad, to assess the ability of gibberellic acid to mitigate the effects of drought on wheat. Nine different treatment combinations were tested in the field using randomized complete block design (RCBD) with split plot arrangement, each treatment having three replications. Treatment combinations was including three different levels of the gibberellic acid application (0 mgL^{-1}, 100 mgL^{-1} and 200 mgL^{-1}) at different growth stages of wheat by skipping irrigation. Control (4 irrigations), skip water at booting stage and skip water at grain formation stage.

Results of the experiment showed that maximum plant height (113.03 cm) with skip irrigation at grain formation stage with a gibberellic acid application 200 mg L^{-1} while the minimum plant height were recorded in control irrigation with application of gibberellic acid 100 mgL^{-1} (106.87 cm).

The maximum spike length (13.400 cm) with skip irrigation at grain formation stage (W_2) and minimum spike length with control irrigation (11.147 cm),maximum 1000-grain weight with skip irrigation at grain formation stage (42.047 g) while th e minimum with control irrigation (37.877 g), grain protein maximum (13.340 %) with skip irrigation at grain formation stage while the minimum protein content with control irrigation and in treatment with skip irrigation at grain formation stage (W2) wheat grain yield was maximum (5.8200 kg ha^{-1}) with 200 mgL^{-1} gibberellic acid application and minimum in control (4 irrigation) with grain yield (4.0733 kg ha^{-1}) with 0 mg L^{-1} gibberellic acid application and with Skip irrigation at booting stage (W1) wheat grain yield production was (4.8967 kg ha^{-1}) with 100 mg L^{-1}. Finding of this study suggested that skip irrigation at grain formation stage with application of gibberellic acid 200 mg L^{-1} give more yield as compared to skip irrigation at booting stage and control.

5. CONCLUSIONS

The experiment results revealed that the drought stress hampered the yield and productivity of wheat drastically but exogenous application of gibberellic acid play a vital role to mitigate the effect of drought stress in wheat (*Triticum aestivum*). This study investigated the interactive effects of gibberellic acid (GA3) and water regimes on wheat yield and yield components.

Results demonstrated significant positive effects of GA3 application on plant height, spike length, 1000-grain weight, grain protein content, harvest index, and inter-nodal length. The highest values for most parameters were observed with 200 mg L^{-1} GA3, particularly under the skip irrigation at the grain formation stage. These findings suggest that GA3 can partially mitigate the negative impacts of water stress on wheat growth and yield. However, the interaction between GA3 and water regimes was significant for some parameters, indicating that the optimal GA3 application rate may vary depending on the specific water stress scenario.

This study was conducted under specific environmental conditions and with a single wheat cultivar. Further research is needed to validate these findings across different environments, cultivars, and with a wider range of GA3 concentrations and water stress levels. Future studies should investigate the physiological mechanisms underlying the observed responses to GA3 and water stress. Exploring the combined effects of GA3 with other agronomic practices, such as improved nutrient management and the use of biofertilizers, could further enhance wheat productivity under water-limited conditions.

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