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Evaluating the Effects of Potassium and Naphthalene Acetic Acid on Drought Tolerance of Wheat

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Abstract

Wheat productivity in semi-arid and rainfed regions is severely affected by drought stress, which limits growth, physiological efficiency, and yield. A field study was conducted during the Rabi season 2024–2025 at the University Research Farm, Koont (Pothowar region, Punjab, Pakistan) to evaluate the effects of foliar-applied Naphthalene Acetic Acid (NAA) and Potassium Nitrate (KNO₃) on growth, physiological traits, drought tolerance, and yield performance of wheat. The experiment was conducted using a Randomised Complete Block Design (RCBD) with eight treatments and three replications. Treatments comprised: T₁ (Control), T₂ (NAA 50 ppm), T₃ (NAA 100 ppm), T₄ (NAA 150 ppm), T₅ (KNO₃ 2%), T₆ (NAA 150 ppm + KNO₃ 2%), T₇ (NAA 100 ppm + KNO₃ 2%), and T₈ (NAA 50 ppm + KNO₃ 2%). Foliar applications were applied at the tillering and booting stages. Data were recorded for chlorophyll content, crop growth rate, plant height, spike length, number of grains per spike, 1000-grain weight, and grain yield. The results showed that the combined application of NAA and potassium significantly improved physiological and yield parameters compared to individual applications and control treatment. The highest grain yield was recorded in treatment T₆ (NAA 150 ppm + KNO₃ 2%), which produced significantly higher chlorophyll content and crop growth rate. Chlorophyll content ranged from 34.06 (T₁) to 41.09 (T₆). Values for T₂, T₃, T₄, T₅, T₇, and T₈ were 35.93, 37.02, 38.48, 40.11, 38.22, and 38.98, respectively. Crop growth rate increased from 8.51 g m⁻² day⁻¹ in control to 13.64 g m⁻² day⁻¹ in T₆, while T₂, T₃, T₄, T₅, T₇, and T₈ recorded 10.05, 10.50, 11.86, 12.87, 11.88, and 12.45 g m⁻² day⁻¹, respectively. Plant height improved from 85.16 cm (T₁) to 102.81 cm (T₆). Other treatments produced heights of 89.88 cm (T₂), 93.13 cm (T₃), 95.82 cm (T₄), 98.57 cm (T₅), 95.34 cm (T₇), and 98.66 cm (T₈). Spike length plant⁻¹ increased from 8.33 cm (T₁) to 11.02 cm (T₆), with intermediate values of 9.07, 9.19, 9.85, 10.56, 10.01, and 10.21 cm under T₂, T₃, T₄, T₅, T₇, and T₈, respectively. Spikelets spike⁻¹ ranged from 13.94 (T₁) to 18.68 (T₆), while T₂, T₃, T₄, T₅, T₇, and T₈ recorded 15.00, 15.96, 17.01, 18.06, 16.97, and 17.96 spikelets spike⁻¹, respectively. The highest 1000-grain weight (43.40 g), grain yield (4655.85 kg ha⁻¹), biological yield (10327.94 kg ha⁻¹), and harvest index (44.84%) were obtained in T₆, whereas control plots recorded 36.83 g, 3216.27 kg ha⁻¹, 8210.08 kg ha⁻¹, and 38.77%, respectively. Grain yield under T₂, T₃, T₄, T₅, T₇, and T₈ was 3459.97, 3701.05, 4195.93, 4506.53, 4351.55, and 4506.53 kg ha⁻¹, respectively. The results were statistically significant at P ≤ 0.05. The improvement in yield may be attributed to enhanced stomatal regulation, osmotic adjustment, and improved nutrient uptake under drought conditions. The improvement in growth and yield parameters under integrated treatment may be attributed to improved photosynthetic efficiency, osmotic adjustment, water use efficiency, and better assimilate partitioning under drought stress conditions. The study concluded that the integrated application of potassium and auxin is an effective strategy for improving wheat productivity under drought stress conditions and can be recommended for semi-arid and rainfed agricultural systems.

Keywords: Wheat, Potassium, Naphthalene Acetic Acid, Foliar application, Grain yield, Growth attributes, Rainfed agriculture, Drought stress, Water Use Efficiency, Crop Growth Rate.

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Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple crops, supplying essential calories and nutrients to over one-third of the global population. Creating favourable growing conditions is necessary to achieve high yield and quality. Pakistan is largely an agricultural country, where the sector contributes substantially to GDP and provides about 37.4% of employment (Pakistan Economic Survey, 2023). Punjab produces nearly 76% of the nation's annual food grains (USDA Foreign Agriculture Service Report, 2014). Within Punjab, the Pothwar region, comprising Rawalpindi, Chakwal, Jhelum, Murree, and Attock, possesses unique agro-climatic conditions that are important for agricultural production.

Wheat is a vital cereal crop globally, providing calories to millions and supporting food security (Farooq, Hussain, and Siddique, 2019). Its production is highly threatened by environmental stresses, especially drought, which limits water availability, disrupts physiological functions, reduces growth and photosynthesis, and causes major yield losses (Bita and Gerats, 2019; Fahad et al., 2018). Increasing drought frequency due to climate change emphasises the need for effective management strategies (Lobell et al., 2019).

Potassium deficiency increases vulnerability to water loss, disrupts carbohydrate metabolism, and weakens antioxidative defence, ultimately reducing plant survival during drought (Wang et al., 2021). Similarly, naphthalene acetic acid (NAA), a synthetic auxin, has been widely studied for its role in regulating plant responses to environmental stresses (Ashraf, Akram, and Al-Qurainy, 2018). NAA influences key physiological processes such as cell elongation, root development, and stress signalling

pathways (Iqbal et al., 2021). Studies have shown that auxin application can improve root architecture by promoting root elongation and branching, thereby enhancing water uptake under drought conditions (Khan et al., 2021). In addition, NAA has been reported to stimulate antioxidant activity, which helps detoxify reactive oxygen species (ROS) generated during drought stress (Fariduddin, Mirza, and Ali, 2020).

Although the individual benefits of potassium and NAA are well documented, studies evaluating their combined and synergistic effects on drought tolerance in wheat remain limited (Zulfiqar et al., 2021). Understanding this interaction is important because the physiological pathways regulated by potassium and auxins overlap in water retention, stress signalling, and antioxidative mechanisms (Ali et al., 2019). Drought tolerance in wheat is a complex trait controlled by genetic, physiological, and biochemical factors, including stomatal conductance, photosynthetic pigment concentration, osmolyte accumulation, biomass production, and grain filling (Farooq et al., 2018; Aslam et al., 2021). Potassium helps maintain turgor pressure and enzyme activity related to carbon assimilation, whereas NAA supports cell growth and regulates stress-responsive genes (Iqbal et al., 2021; Shahzad et al., 2020).

Drought stress is one of the most important environmental factors limiting wheat productivity worldwide, particularly in semi-arid and rainfed regions. Water deficit conditions reduce photosynthesis, nutrient uptake, and grain formation, ultimately resulting in significant yield losses. Recent studies have reported that potassium plays a vital role in improving drought tolerance by regulating stomatal movement, osmotic

adjustment, enzyme activation, and photosynthesis under water stress conditions (Ahanger et al., 2020; Hasanuzzaman et al., 2020). Similarly, plant growth regulators such as auxin improve root development, nutrient uptake, and assimilate partitioning, which enhances crop growth and yield under stress conditions (Khan et al., 2020). Integrated application of nutrients and plant growth regulators has been reported to be more effective than their individual application for improving crop growth, chlorophyll content, crop growth rate, and grain yield under drought stress conditions (Ali et al., 2021). Therefore, integrated hormonal and nutrient management can be considered an effective strategy for improving wheat productivity under drought-stressed environments.

The objectives of the present study were to evaluate the integrated effects of naphthalene acetic acid and potassium nitrate on growth, physiological traits, and yield of wheat under drought conditions. The study aimed to determine whether combined foliar application performs better than individual applications and to identify the optimum concentration for improving drought tolerance and yield performance. It was hypothesised that the combined application of NAA and potassium would enhance physiological efficiency, chlorophyll content, crop growth rate, and ultimately grain yield under moisture stress conditions.

Materials and Methods

Experimental Site

The field experiment was conducted during the Rabi season of 2024–2025 at the University Research Farm, Koont, in the Pothowar region of Punjab, Pakistan. The area has a semi-arid climate with low and irregular rainfall, while the soil is loamy to sandy loam, moderately fertile, and

slightly alkaline, conditions suitable for wheat cultivation.

Soil Analysis

Analysis of the surface soil (0–30 cm) revealed important information about its fertility status. The soil had an EC of 1.35 dS m⁻¹, indicating mild salinity, which may slightly affect sensitive crops but is generally suitable for farming. The pH of 7.38 reflects a neutral reaction, promoting optimal nutrient uptake by plants. Organic matter content was low (0.72%), suggesting the need for organic amendments such as farmyard manure or compost to improve soil structure and biological activity. Available phosphorus was extremely low (2.2 mg kg⁻¹), indicating that phosphorus fertilisation is essential for proper crop growth, while potassium content (81 mg kg⁻¹) was moderate, providing a reasonable nutrient supply. The soil texture was loam, favourable for most field crops due to good aeration and moisture retention, and the saturation percentage of 37% indicated balanced soil moisture. Overall, the results emphasise the importance of balanced fertilisation and the addition of organic matter to maintain soil health and enhance crop yield potential.

Experimental Design and Treatments

The experiment was arranged in a Randomised Complete Block Design (RCBD) with eight treatments and three replications, using plots of 4 m × 4 m and a net harvestable area of 3 m × 3 m to minimise border effects. Wheat (*Triticum aestivum* L.) was used as the test crop to evaluate the effects of foliar-applied potassium (K) and Naphthalene Acetic Acid (NAA) on growth and yield. All treatments were applied at the tillering stage (45 days after sowing) and again at the booting stage (75 Days After Sowing), and data were recorded at appropriate growth stages under uniform agronomic

practices. The study comprised eight treatments, which were the sole and combined foliar applications of Potassium Nitrate (KNO_3) and Naphthalene Acetic Acid (NAA). Treatments included (T1) Control, (T2) Naphthalene Acetic Acid applied @ of 50 ppm, (T3) Naphthalene Acetic Acid applied @ of 100 ppm, (T4) Naphthalene Acetic Acid applied @ of 150 ppm, (T5) KNO_3 applied @ 2%, (T6) Naphthalene Acetic Acid applied at rate of 50 ppm + KNO_3 applied @ 2%, (T7) Naphthalene Acetic Acid applied at rate of 100 ppm + KNO_3 applied @ 2%, (T8) Naphthalene Acetic Acid applied at rate of 150 ppm + KNO_3 applied @ 2%.

Foliar sprays were applied twice during the crop cycle, first at the active tillering stage (45 Days After Sowing) and again at the booting stage (75 Days After Sowing). Fresh treatment solutions were prepared on the day of application using distilled water with 20 (0.1% v/v) to improve leaf adhesion. Spraying was carried out in the early morning with a calibrated knapsack sprayer to ensure uniform coverage and prevent drift between plots.

Drought stress conditions were created by limiting irrigation at critical growth stages, particularly during tillering and grain filling stages. Soil moisture was allowed to decline naturally to create moisture deficit conditions typical of semi-arid environments. These conditions allowed evaluation of treatment performance under drought stress conditions.

Statistical Analysis

The collected data were analysed statistically using analysis of variance (ANOVA) under Randomised Complete Block Design (RCBD). Treatment means were compared using the Least Significant Difference (LSD) test at 5% probability level (Steel & Torrie, 1997). Statistical

analysis was performed using Statistix 8.1 software. The assumptions of ANOVA, including normality and homogeneity of variance, were checked before analysis.

The following parameters were studied: Chlorophyll Content (SPAD Meter):

A chlorophyll meter (SPAD-meter) was employed to determine the quantity of Chlorophyll in the plant leaves. The value of the relative SPAD meter that is obtained when the SPAD meter is measured is proportional to the chlorophyll content of the leaf (Ling et al., 2011).

Crop Growth Rate:

This rate of increase in grams per unit area per unit time of the dry matter is referred to as the crop growth rate. The average growth rate of the crop during the time period T1 and T2 can be obtained by the following formula (Laghari et al., 2010).

$$\text{CGR} = \frac{W_2 - W_1}{[A(T)]_2 - T_1} (\text{gm}^{-2}\text{day}^{-1})$$

Plant Height:

Ten random plants were measured with the help of the meter rod and calculated in terms of height. The distance between the height of the tallest spike and the base was determined using the base.

Spike Length:

A random plant was selected, and the length of the spikes of the plant was measured using a ruler. This was measured from the base to the end of the spike.

Spikelet Number Spike⁻¹:

Individuals spikelet's number per spike was calculated by hand on the randomly sampled plants.

1000 Grain Weight (g):

Seed was being sampled randomly and weighed. Divide the amount of seed in that sample, and then, we can obtain the weight of 1000 seeds by using the use of formula:

$$1000 - \text{Seed WeigWeight Sample (g)} \times 1000$$

Grain Yield (kg ha⁻¹):

Grain yield is the number of grains per acre of the land area. It is generally measured in kilograms per hectare (kg/ha) or bushels per acre (bu/acre). To determine the seed yield: Select all the plants of wheat within a certain size (e.g. one square meter). Blow the grain away to get the grains out of the plant. Weigh up the grains obtained. Divide by the conversion factor the weight of grains to get the yield per unit area (e.g. in case you harvested on one square meter, convert it to kg ha⁻¹). Formula:

$$\text{Grain yield} = \frac{\text{Weight of grains harvested from sample area}}{\text{Sample area in hectares}} \times 10,000$$

Biological Yield:

Biological yield can be regarded as the portion of the total dry mass which is generated by the crop, or grains, straw and other above-ground biomass. This is also estimated as kilograms/hectare (kg ha⁻¹). To make the biological yield: Cut out all the above-ground parts of the wheat plants of an area. Shivel the harvested material to remove the moisture. Measure obtained total dry biomass. The weight of dry biomass is multiplied by the factor of conversion in order to get the yield per unit area.

$$\text{Biological yield} = \frac{\text{Weight of dry biomass harvested from sample area}}{\text{Sample area in hectares}} \times 10,000$$

Harvest Index:

The Harvest index will be calculated by the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100$$

Results and Discussions

Physiological Parameters

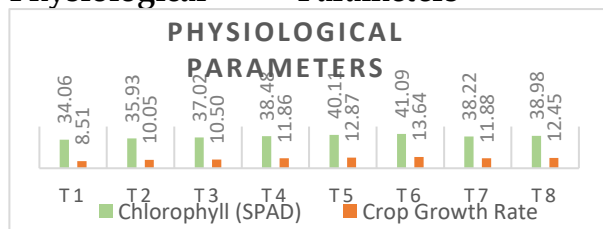


Figure 1. Effect of Different Treatments on Chlorophyll Content (SPAD) and Crop Growth Rate of Wheat

Chlorophyll Content (SPAD)

Chlorophyll content increased progressively across treatments, ranging from 34.06 SPAD in T1 (Control) to a maximum of 41.09 SPAD in T6 (NAA 150 ppm + KNO₃ 2%). Treatments T2 (35.93), T3 (37.02), and T4 (38.48) showed steady improvement, while T5 (40.11) remained statistically close to the highest treatment. NAA alone also enhanced chlorophyll, as T7 and T8 recorded 38.22 and 38.98 SPAD, respectively, but these values were still lower than the combined treatments. The increase in chlorophyll suggests improved nitrogen assimilation and delayed leaf senescence, which directly supports photosynthetic capacity. Chlorophyll content was significantly improved by the application of potassium and auxin under drought stress conditions. The highest chlorophyll content (41.09 SPAD) was observed in treatment T6, indicating improved photosynthetic efficiency under integrated nutrient and hormonal application. The increase in chlorophyll content under potassium application may be due to its role in enzyme activation, chloroplast stability, and photosynthetic processes under water deficit conditions (Ahanger et al., 2020). Similar findings were reported by Vinaya Kumar Yadav et al. (2019), who observed that foliar potassium nitrate significantly improved physiological traits and biochemical efficiency in wheat under field conditions, resulting in healthier foliage and better photosynthetic activity. Furthermore, Kenaway and Bughdady (2021) demonstrated that exogenous NAA enhanced wheat tolerance and growth under calcareous soils, leading to improved plant vigour. The higher chlorophyll observed in the combined treatments of the

present study, therefore, reflects a synergistic interaction between auxin-regulated metabolic processes and potassium-driven stomatal regulation.

Crop Growth Rate ($\text{g m}^{-2} \text{day}^{-1}$)

Crop growth rate followed a pattern similar to chlorophyll content, confirming the close relationship between photosynthesis and biomass production. The lowest growth rate was recorded in T1 ($8.51 \text{ g m}^{-2} \text{day}^{-1}$), whereas T6 achieved the highest value ($13.64 \text{ g m}^{-2} \text{day}^{-1}$). Intermediate increases were observed in T2 (10.05), T3 (10.50), T4 (11.86), and T5 (12.87), highlighting that gradual increases in NAA concentration combined with potassium nitrate enhanced dry matter accumulation. Treatments with NAA alone, T7 (11.88) and T8 (12.45), also performed better than the control, but were less effective than integrated applications. Crop growth rate was also significantly affected by different treatments. The maximum crop growth rate ($13.64 \text{ g m}^{-2} \text{day}^{-1}$) was recorded in treatment T6, which indicated improved biomass accumulation under integrated nutrient and hormonal management. The improvement in crop growth rate may be attributed to better nutrient uptake, enhanced photosynthesis, and improved water use efficiency under drought stress conditions (Ali et al., 2021). These findings align with Rashid Khan et al. (2024), who reported that combining growth regulators with nutrients enhanced wheat growth via cell division and elongation. Yadav et al. (2019) noted that potassium improved enzyme activity and water relations, boosting biomass and growth rate. The improvement in growth and yield due to NAA application may be associated with enhanced cell elongation, cell division, and improved source-sink relationship. Auxins are known to regulate physiological processes, including photosynthesis, assimilate translocation, and stomatal

activity. Potassium plays a vital role in stomatal regulation, osmotic adjustment, enzyme activation, and maintenance of plant water relations under drought stress conditions. The combined application of NAA and potassium may have synergistically improved physiological efficiency, leading to higher chlorophyll content, crop growth rate, and grain yield under drought stress conditions. These findings are consistent with previous studies where integrated nutrient and plant growth regulator application improved drought tolerance and productivity in wheat.

Morphological Parameters

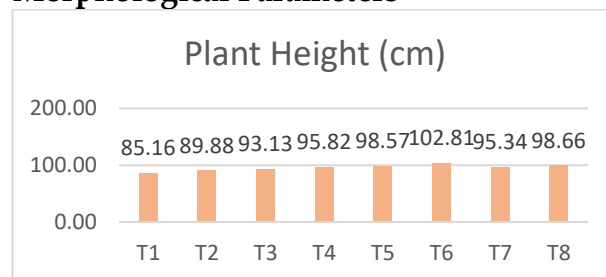


Figure 2. Effect of Different Treatments on Plant Height (cm) of Wheat

Plant Height (cm):

Plant height of wheat responded significantly to the application of Naphthalene Acetic Acid (NAA) and potassium nitrate (KNO_3), highlighting the positive role of growth regulators and nutrient supplementation in vegetative development. The shortest plants were recorded in T1 (Control) with 85.16 cm, while a gradual increase was observed in all treated plots. Plant height increased to 89.88 cm in T2, 93.13 cm in T3, 95.82 cm in T4, and 98.57 cm in T5. The tallest plants were obtained in T6 (NAA 150 ppm + KNO_3 2%) with 102.81 cm, indicating a strong synergistic effect of higher auxin concentration with potassium nutrition on cell elongation and stem growth. Treatments with NAA alone, T7 and T8, also showed improved plant height with 95.34 cm and 98.66 cm, respectively, but

remained slightly lower than the combined treatment. The improvement in plant height may be attributed to enhanced meristematic activity, increased cell division, improved nutrient translocation, enzyme activation, and better water regulation. These findings are supported by [Yadav et al. \(2019\)](#), who reported that foliar application of potassium nitrate significantly increased plant height in wheat through improved physiological efficiency and nutrient uptake. Likewise, Kenaway and [Bughdady \(2021\)](#) observed that exogenous NAA application stimulated vegetative growth and produced taller wheat plants by improving hormonal balance. Similarly, [Khan et al. \(2024\)](#) concluded that integrating plant growth regulators with balanced fertilisation markedly enhanced wheat growth traits, particularly plant height. Therefore, the superior performance of T6 suggests that higher doses of NAA combined with potassium nitrate create optimal internal conditions for structural development, leading to stronger plant architecture and greater yield potential.

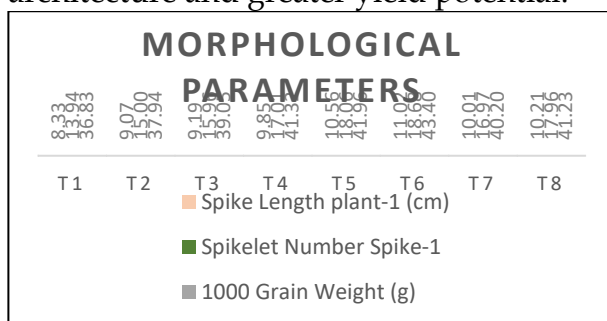


Figure 3. Effect of Different Treatments on Morphological Parameters of Wheat (Spike Length plant⁻¹, Spikelet Number spike⁻¹ and 1000-Grain Weight (g))

Spike Length Plant⁻¹ (cm)

Spike length of wheat improved noticeably with the application of Naphthalene Acetic Acid (NAA) and potassium nitrate (KNO₃). The shortest spikes were recorded in the control (T1 = 8.33 cm), while T2 (9.07 cm) and T3 (9.19 cm)

showed moderate increases with NAA at a lower concentration and potassium alone. Combined treatments produced longer spikes, with T4 = 9.85 cm, T5 = 10.56 cm, and the maximum in T6 (NAA 150 ppm + KNO₃ 2%) = 11.02 cm, demonstrating the effectiveness of higher auxin combined with potassium. NAA alone, T7 (10.01 cm) and T8 (10.21 cm), also improved spike length but remained slightly lower than the combined treatments. Enhanced spike length is linked to better assimilation partitioning and reproductive growth. These results are supported by [Khan et al. \(2024\)](#), who reported that growth regulators with balanced fertilisation improve spike traits, and Kenaway and [Bughdady \(2021\)](#), who found that auxin application promotes floral development and spike elongation through enhanced metabolic activity.

Spikelets Number Spike⁻¹

The number of spikelets per spike increased significantly with Naphthalene Acetic Acid (NAA) and potassium (KNO₃) application. The control (T1) produced 13.94 spikelets, while T2 and T3 recorded 15.00 and 15.96, respectively. Further improvement was observed in T4 (17.01) and T5 (18.06), with the highest in T6 = 18.68, followed by T8 (17.96) and T7 (16.97). The increase is attributed to improved nutrient transport, photosynthetic efficiency, and hormonal balance. These results align with [Yadav et al. \(2019\)](#) and [Tariq et al. \(2024\)](#), who reported enhanced spikelet formation through potassium fertilisation and auxin-based growth regulators.

1000-Grain Weight (g)

Treatment with Naphthalene Acetic Acid (NAA) and potassium (KNO₃) significantly increased 1000-grain weight, reflecting better grain filling. The lowest weight was in T1 (36.83 g), while T2 and T3 recorded 37.94 g and 39.05 g. Combined

treatments enhanced weight further, with T4 = 41.32 g, T5 = 41.96 g, and the highest in T6 = 43.40 g. NAA alone (T7 = 40.20 g; T8 = 41.23 g) improved weight but remained lower than integrated treatments. This increase is linked to enhanced photosynthesis and enzyme activity, consistent with Khan et al. (2024) and Yadav et al. (2019).

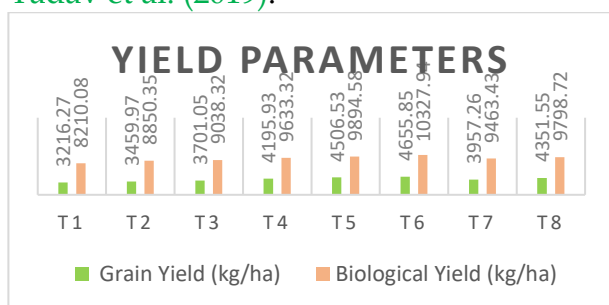


Figure 4. Effect of Different Treatments on Grain and Biological Yield of Wheat
Grain Yield (kg ha⁻¹):

The grain yield varied significantly among the treatments, ranging from 3216.27 kg ha⁻¹ in T1 (control) to 4655.85 kg ha⁻¹ in T6, indicating the positive effect of applied treatments on crop productivity. The lowest yield in T1 aligns with findings by Khan et al. (2021), who reported that untreated plots or basal fertilisation alone produced the least grain yield in cereal crops. Treatments T2, T3, and T4 showed gradual increases in grain yield (3459.97, 3701.05, and 4195.93 kg ha⁻¹, respectively), highlighting the beneficial effect of integrated nutrient management and foliar applications, consistent with Ahmed and Ali (2020), who observed enhanced grain production with foliar nutrient supplementation. Maximum grain yield was recorded in T6 (4655.85 kg ha⁻¹), followed by T8 (4351.55 kg ha⁻¹) and T5 (4506.53 kg ha⁻¹), indicating that these treatments likely provided optimal nutrient availability and improved plant physiological performance. Grain yield was significantly influenced by different treatments under drought stress

conditions. The highest grain yield was recorded in treatment T6, which showed an increase of 61.7% compared to the control treatment. The increase in grain yield under integrated application of potassium and auxin may be attributed to improved photosynthetic activity, better nutrient uptake, and enhanced assimilate translocation towards grains under moisture stress conditions. Similar results were reported by Hasanuzzaman et al. (2020), who observed that potassium application significantly improved wheat yield under drought stress by improving water use efficiency and photosynthesis. These findings correlate with Shah et al. (2019), who demonstrated that combined organic and inorganic fertilisation significantly increased grain yield in cereal crops compared to single-source applications.

Biological Yield (kg ha⁻¹)

Biological yield, which includes total above-ground biomass, followed a similar trend to grain yield, with the highest biomass in T6 (10327.94 kg ha⁻¹) and the lowest in T1 (8210.08 kg ha⁻¹). The increment in biomass with treated plots suggests enhanced vegetative growth and photosynthetic efficiency due to nutrient supplementation, corroborating Hussain et al. (2020), who reported improved biological yield with integrated nutrient management in cereal crops. Treatments T4 (9633.32 kg ha⁻¹), T5 (9894.58 kg ha⁻¹), T7 (9463.43 kg ha⁻¹), and T8 (9798.72 kg ha⁻¹) also demonstrated substantial increases in biomass production, indicating that both foliar applications and combined fertilisation strategies contributed significantly to plant growth. These results are in agreement with Khalid and Zubair (2018), who highlighted that both organic and chemical inputs improve vegetative biomass, ultimately supporting higher grain production.

Harvest Index (%)

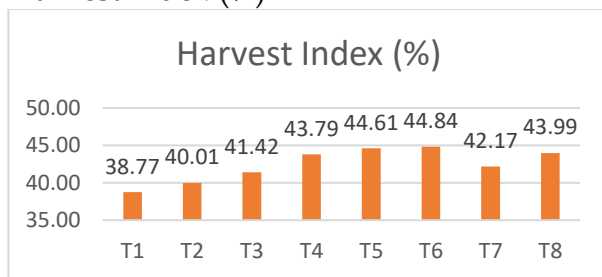


Figure 5. Effect of Different Treatments on Harvest Index (%) of Wheat

Application of Naphthalene Acetic Acid (NAA) and potassium (KNO_3) significantly influenced the harvest index of wheat under drought conditions, indicating improved biomass conversion into grain yield. The lowest harvest index was recorded in the control treatment (T1 = 38.77%), while NAA application alone progressively increased values to 40.01% (T2), 41.42% (T3), and 43.79% (T4). Potassium alone (T5) further improved the harvest index to 44.61%, reflecting its role in stomatal regulation, osmotic adjustment, and assimilate translocation during grain filling. The highest harvest index was observed in T6 (NAA 50 ppm + KNO_3 2%) with 44.84%, showing a strong synergistic effect of combined application under drought stress. Slightly lower values were recorded in T7 (42.17%) and T8 (43.99%), though both remained higher than the control. The improvement may be attributed to enhanced photosynthetic efficiency, nutrient uptake, and better translocation of assimilates toward grain development. Harvest index was significantly improved by the integrated application of potassium and auxin, and the highest harvest index (44.84%) was recorded in treatment T6. The improvement in harvest index indicates better assimilate partitioning towards grains rather than vegetative parts. Potassium plays an important role in the translocation of photosynthates from source to sink, which ultimately improves

grain filling and harvest index under drought stress conditions (Hasanuzzaman et al., 2020). Ahmad et al. (2021) reported that potassium improved wheat harvest index under water stress by enhancing osmotic adjustment and grain filling. Hassan et al. (2022) found auxin-based regulators enhanced assimilate partitioning and reproductive efficiency. Iqbal et al. (2023) observed that combined nutrient and growth regulator management boosted harvest index and yield under drought. Similarly, Khan et al. (2024) documented that potassium with growth regulators improved drought tolerance and yield traits via enhanced photosynthesis and assimilate translocation.

Statistical Data of measured parameters:

All the parameters recorded were statistically significant ($p \leq 0.05$) with fertiliser treatments except where otherwise noted. Mean comparisons were calculated through the Least Significant Difference (LSD). Test and coefficients of variation (CV%) were kept within tolerable levels, meaning trustworthiness of the experimental data (Steel & Torrie, 1997).

Physiological Parameters:

Application of Naphthalene Acetic Acid (NAA) and potassium (KNO_3) significantly improved chlorophyll content and crop growth rate (CGR) of wheat under drought conditions at $P \leq 0.05$. Chlorophyll content (SPAD) ranged from 34.06 to 41.09, with the lowest value in the control (T1 = 34.06). NAA alone progressively increased chlorophyll content to 35.93 (T2), 37.02 (T3), and 38.48 (T4), while potassium alone (T5) further enhanced it to 40.11 SPAD. The highest chlorophyll content was recorded in T6 (NAA 50 ppm + KNO_3 2%) = 41.09 SPAD, whereas T7 and T8 showed 38.22 and 38.98 SPAD, respectively. Similarly, CGR showed significant variation, with the

lowest value in the control (8.507 g m⁻² day⁻¹). NAA alone increased CGR to 10.048 (T2), 10.497 (T3), and 11.860 (T4), while potassium alone (T5) produced 12.875 g m⁻² day⁻¹. The highest CGR was observed in T6 = 13.642 g m⁻² day⁻¹, followed by 11.879 (T7) and 12.453 (T8). The improvement in chlorophyll content and CGR may be attributed to enhanced enzyme activation, stomatal regulation, nutrient uptake, hormonal balance, and protection of the photosynthetic apparatus under drought stress. Similar findings were reported by Wang et al. (2020), Lotfi et al. (2022), Larouk et al. (2021), and Naseer et al. (2024), who highlighted the positive role of potassium and growth regulators in improving the physiological performance of wheat under water deficit conditions.

Morphological And Yield Parameters:

Application of Naphthalene Acetic Acid (NAA) and potassium (KNO₃) significantly improved plant growth and yield attributes of wheat under drought stress at P ≤ 0.05. Plant height ranged from 85.16 to 102.81 cm, with the lowest value in the control (T1 = 85.16 cm) and the highest in T6 (NAA 50 ppm + KNO₃ 2%) = 102.81 cm, showing a 20.7% increase over the control. NAA alone progressively increased plant height in T2, T3, and T4, while potassium alone (T5) also produced a marked improvement. Spike length showed similar variation, ranging from 8.89 cm in T1 to 10.63 cm in T6, indicating enhanced reproductive growth under treatment application. Grain yield differed significantly among treatments, with the lowest yield in the control (2816.97 kg ha⁻¹) and the highest in T6 = 4555.76 kg ha⁻¹, representing a 61.7% increase over the control. Potassium alone (T5) and T8 also produced comparable yields. Harvest index ranged from 38.77% in T1 to 44.84% in T6, while biological yield increased from 7210 kg ha⁻¹ in T1 to 10287 kg ha⁻¹ in T6, showing a 42.7% increase. The number of

spikelets per spike also improved from 13.45 in T1 to 18.68 in T6, while thousand-grain weight increased from 36.83 g in T1 to 44.29 g in T8. The improvement in growth and yield components under the combined application of NAA and potassium may be attributed to enhanced cell elongation, improved nutrient uptake, better photosynthetic efficiency, and effective assimilate translocation under drought stress. Similar findings were reported by Wang et al. (2020), Hassan et al. (2022), Zörb et al. (2021), and Iqbal et al. (2023), who highlighted the positive role of potassium fertilisation and auxin-based growth regulators in improving wheat performance under water-deficit conditions.

Table 1. Investigating the effect of different treatments on Physiological parameters of Wheat.

Treatment	C.C (SPAD)	C.G.R
T1 (Control)	34.06 ^e	8.507 ^g
T2	35.93 ^{de}	10.048 ^f
T3	37.02 ^{cd}	10.497 ^e
T4	38.48 ^{bc}	11.860 ^d
T5	40.11 ^{ab}	12.875 ^b
T6	41.09 ^a	13.642 ^a
T7	38.22 ^{bc}	11.879 ^d
T8	38.98 ^{bc}	12.453 ^c
LSD (0.05 %)	0.82	0.25
CV (%)	4.2	3.9

C.C (SPAD)= Chlorophyll content; C.G.R = Crop Growth Rate. Treatment means were separated with the Duncan Multiple Range Test at 5% probability. Different letters on treatment means within each column show statistical differences at P≤0.05.)

Table 2. Effect of different treatments on the yield and Yield attributes parameters of Wheat.

TREA TME NT	P. H	S. L (C M)	G. Y (kg ha ⁻¹)	H. I	B. Y	S. N. P.S	10 00 - G. W
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T1 (CON TROL)	85. 16 ^e	8. 89 f	281 6.9 7 ^f	38 .7 7 ^f	72 10 g	13. 45 ^g	36 .8 3 ^h
T2	89. 88 de	9. 47 e	305 9.9 7 ^e	40 .0 1 ^e	82 50 ^f	14. 80 ^f	37 .9 4 ^g
T3	93. 13 ^c d	9. 98 c	340 1.0 3 ^d	41 .4 2 ^d	90 08 e	15. 55 ^e	39 .0 5 ^f
T4	95. 82 ^b c	10 .0 1 ^c	410 5.9 3 ^b	43 .7 9 ^b	96 85 c	17. 01 ^c	41 .2 2 ^d
T5	98. 57 ^a b	10 .5 5 ^a	453 0.9 3 ^a	44 .6 1 ^a	99 94 b	18. 03 ^b	41 .9 6 ^c
T6	10 2.8 1 ^a	10 .6 3 ^a	455 5.7 6 ^a	44 .8 4 ^a	10 28 7 ^a	18. 68 ^a	43 .4 0 ^b
T7	95. 34 ^b c	9. 70 d	365 7.2 6 ^c	42 .1 7 ^c	94 56 d	16. 57 ^d	40 .2 0 ^e
T8	98. 66 ^a b	10 .2 2 ^b	455 1 ^a	43 .9 9 ^b	97 86 c	17. 49 ^c	44 .2 9 ^a
LSD (0.05 %)	6.5 7	0. 39	214	0. 95	27 6	0.6 0	0. 85
CV (%)	4	4. 8	3.6	3. 9	4. 3	4.2	3. 6

P.H = Plant Height; S.L plant⁻¹= Spike Length; S.N.P.S = Spikelet No per spike; 1000-G. W = 1000- Grain Weight; G. Y = Grain yield (kg/ha); H. I = Harvest index; B. Y = Biological yield. Treatment means were separated with the Duncan Multiple Range Test at 5% probability. Different letters on treatment means within each column show statistical differences at P≤0.05.)

Discussion

The present study demonstrated that the integrated application of potassium (KNO₃) and naphthalene acetic acid (NAA) significantly enhanced the physiological, morphological, and yield attributes of wheat under drought stress. Among all treatments, the combined application (T6) proved most effective, highlighting a strong synergistic

interaction between nutrient management and hormonal regulation in mitigating water-deficit stress.

The significant increase in chlorophyll content under T6 (41.09 SPAD) indicates improved photosynthetic efficiency and delayed leaf senescence. Drought stress commonly causes chlorophyll degradation due to oxidative damage, but potassium helps maintain chloroplast structure, regulate stomatal function, and activate enzymes, sustaining photosynthesis under stress (Ahanger et al., 2020). Auxin contributes by regulating gene expression and promoting cell growth, further stabilising chlorophyll.

Crop growth rate (CGR) was also highest in T6 (13.64 g m⁻² day⁻¹), reflecting enhanced biomass accumulation through improved photosynthesis and efficient resource use. Potassium improves enzyme activation, carbohydrate metabolism, and protein synthesis, while auxin stimulates cell division and elongation, together boosting plant growth under limited water availability (Ali et al., 2021).

Grain yield increased substantially under integrated treatment, with T6 showing a 61.7% rise over the control. This improvement is linked to better water use efficiency, nutrient uptake, and assimilate partitioning toward reproductive organs. Potassium supports phloem loading and transport of assimilates, while auxin enhances sink strength by promoting grain development and filling (Hasanuzzaman et al., 2020).

Harvest index, reflecting the efficiency of biomass conversion to grain, was also highest in T6 (44.84%), demonstrating improved assimilate partitioning. Potassium regulates carbohydrate translocation, and auxin promotes reproductive development, optimising yield stability under drought.

Physiologically, the combined application enhances drought tolerance through multiple mechanisms. Potassium supports osmotic adjustment, stomatal regulation, cell turgor, and antioxidant defence, while auxin improves root architecture, increasing water and nutrient uptake. Together, these factors improve both water acquisition and utilisation, enhancing growth and productivity under stress (Khan et al., 2020).

Overall, this study emphasises that effective drought mitigation in wheat requires integrated nutrient and hormonal management. The synergistic use of potassium and NAA improves photosynthesis, water relations, growth, and yield through enhanced assimilate partitioning and reproductive development. This integrated strategy offers a practical approach for improving wheat productivity in semi-arid and drought-prone regions, highlighting the importance of multifaceted agronomic interventions under climate change.

Conclusion

The results of the present study concluded that the integrated application of potassium and auxin significantly improved growth, physiological traits, and yield of wheat under drought stress conditions. The combined treatment improved chlorophyll content, crop growth rate, harvest index, and grain yield compared to the control treatment. The improvement in yield may be attributed to improved osmotic adjustment, better water use efficiency, enhanced photosynthesis, and improved assimilate partitioning under drought stress conditions. Therefore, integrated nutrient and hormonal management can be recommended as an effective strategy for improving wheat productivity in semi-arid and rainfed regions. It can be concluded that foliar application of naphthalene acetic acid and

potassium significantly improved growth, physiological traits, and yield of wheat under drought conditions. Among all treatments, the combined application of NAA 150 ppm + KNO₃ 2% proved to be the most effective treatment in improving chlorophyll content, crop growth rate, and grain yield, plant height, spike length, spikelets per spike, 1000-grain weight, grain yield, biological yield, and harvest index. Treatments T5, T7, and T8 also produced substantial yield improvements, indicating the positive contribution of potassium nutrition and moderate auxin concentrations. Sole NAA applications (T2-T4) improved growth and yield parameters compared to the control, but were less effective than integrated treatments. The study confirms that combined foliar application of NAA and potassium nitrate enhances nutrient assimilation, strengthens source-sink relationships, promotes reproductive development, and maximises grain filling in late-sown wheat under semi-arid conditions. The integrated use of plant growth regulators and potassium nutrition can therefore be recommended as an effective strategy to enhance drought tolerance and wheat productivity under semi-arid conditions. Further research should be conducted under different climatic conditions and locations to validate these findings.

Recommendations

1. Foliar application of NAA at 150 ppm combined with KNO₃ at 2% is recommended at tillering and booting stages for maximising wheat yield under late-sown conditions.
2. Farmers in semi-arid regions similar to Pothowar should adopt integrated foliar nutrient and growth regulator management rather than relying solely on basal fertilisation.
3. Further multi-location and multi-

Season trials are suggested to validate the consistency of results across varying climatic and soil conditions.

4. Future research may focus on evaluating economic feasibility and cost-benefit analysis of combined NAA and potassium nitrate applications for large-scale adoption.
5. Studies integrating additional micronutrients with NAA and potassium may further enhance wheat productivity and stress tolerance.

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