Iran Agricultural Research (2025) 44(2) 110-118

Shiraz University

Iran Agricultural Research

Journal homepage: https://iar.shirazu.ac.ir/?lang=en

Research Article

Effect of foliar application of urea and 6-benzylaminopurine on grain yield and grain nutrient content of durum wheat (*Triticum turgidum* L. *cv.* Saji) under rainfed conditions

Hossein Alihoseini[a], Mohammad Javad Zarea[a*]

[a] Department of Agronomy and Plant Breeding, Faculty of Agriculture, Ilam University, Ilam, I. R. Iran

ARTICLE INFO

Keywords:
6-Bezylaminopurine
Foliar application
Grain yield
Grain Zn content
Urea

Received: 08 March 2025
Revised: 11 September 2025
Accepted: 14 September 2025

ABSTRACT- The benefits of foliar nitrogen feeding and exogenous cytokinin application on wheat performance, particularly their effects on grain yield and grain nutrient content, are of considerable importance. A field experiment was conducted to evaluate the efficacy of foliar urea and 6-benzylaminopurine (6-BAP) application on grain nutrient composition and yield in the 'Saji' wheat cultivar during the 2021–2022 growing season in Sirvan County, Ilam Province, Iran. The experiment followed a 4 × 2 factorial arrangement, with three replications. Urea was foliar-applied at four concentrations (0%, 2%, 3%, and 4%, w/v), while 6-BAP was applied at two levels (0 and 100 mg L^{-1}). Foliar spraying was performed at the late flowering stage. Results indicated that the highest number of grains per spike (37.2) was obtained with the 3% (w/v) urea treatment, while a higher concentration (4%, w/v) negatively affected this trait. The greatest total grain weight per spike (1.77 g) and 1000-grain weight (47.8 g) were achieved with 3% (w/v) urea combined with exogenous 6-BAP application. The maximum grain yield (2180 kg ha^{-1}) was also recorded under this treatment. Additionally, the highest grain nitrogen (1.5%) and Zn (46.2 mg kg^{-1}) contents were observed with 3% urea application. These findings suggest that the foliar application of urea at lower concentrations, in combination with 6-BAP, represents an effective approach for enhancing grain yield and quality in durum wheat.

INTRODUCTION

It is widely recognized that nitrogen (N) is the most crucial nutrient for optimizing crop yield. Grain N content and yield can be maximized by applying nitrogen at key growth stages, as wheat requires a continuous supply of N throughout its growth cycle. Application of nitrogen during the grain-filling stage has been reported to exert a significant positive effect on grain yield (Wang et al., 2023). However, the N requirement and response to N application in wheat depend on the growth stage and duration of the crop cycle. Post-flowering N uptake contributes between 5% and 40% of the total grain N (Taulemesse et al., 2015). Woolfolk et al. (2002) also reported that late-season N applications increase both grain yield and grain N content in wheat. Moreover, the accumulation of seed nitrogen may continue until the end of the seed-filling period (Borghi et al., 1983; Sarandón and Gianibelli, 1992). While post-flowering N uptake plays a significant role in determining grain yield (Kichey et al., 2007), N absorption from the soil tends to decline after flowering (Bingham and Garzon, 2023). In semi-arid regions, rainfall shortages and high temperatures frequently occur during the grain-filling stage, limiting the feasibility of soil-applied nitrogen (top dressing). Consequently, foliar N application has emerged as an effective strategy to meet the plant's nitrogen demand during the post-flowering phase. Several studies have demonstrated that foliar application of N enhances grain protein content (Lyu et al., 2022), maintains wheat productivity (Delfine et al., 2005), and improves photosynthesis, remobilization, and yield (Ru et al., 2024). Additionally, foliar urea application has been shown to improve drought tolerance in wheat and significantly accelerate grain filling (Lv et al., 2021). Cytokinin is one of the five classical phytohormones known to play a pivotal role in plant growth and development. It has been widely used to enhance crop growth and yield, including in wheat (Koprna et al., 2016). Numerous studies have examined the effects of exogenous cytokinin application in wheat (Zarea, 2025b; Faridnia et al., 2024; Zarea and Karimi, 2023; Prasad, 2022). Cytokinin is crucial in regulating the grain-filling process in wheat (Zarea, 2025b) and can delay leaf senescence (Nagar et al., 2015), thereby

*Corresponding Author: Associate Professor, Department of Agronomy and Plant Breeding, Faculty of Agriculture, Ilam University, Ilam, I. R. Iran
E-mail address: mj.zarea@ilam.ac.ir
DOI: 10.22099/iar.2025.52656.1678

maintaining active photosynthesis during the grain-filling stage, an essential factor for achieving higher yields.

Hormone metabolism can be significantly influenced by nitrogen fertilization (Buezo et al., 2019). Although there is evidence indicating that foliar-applied nitrogen and exogenous cytokinin can enhance wheat performance and yield, their combined effectiveness under field rainfed conditions remains uncertain. Previous studies have examined the exogenous application of 6-benzylaminopurine (6-BAP), a synthetic cytokinin, as well as foliar nitrogen application in wheat. However, the interactive effects of 6-BA and varying concentrations of foliar urea applied at the flowering stage on grain yield and nutrient content have received limited attention. Therefore, the present study aimed to elucidate the effects of different foliar urea concentrations, applied with and without 6-BAP, on field-grown durum wheat. Specifically, the study evaluated how various concentrations of foliar urea and 6-BAP (synthetic cytokinin) influence nitrogen (N), phosphorus (P), and zinc (Zn) accumulation in the grain, as well as their impact on grain yield and yield components. All foliar treatments were applied once at the end of flowering, and the plants were grown under rainfed conditions, receiving no irrigation during the grain-filling stage until maturity.

MATERIALS AND METHODS

The experiment was conducted during the 2021–2022 wheat growing season under predominantly rainfed conditions. However, due to the soil dryness, supplemental irrigations were applied during crop establishment and stem elongation. The field experiment was carried out on a farmer's field in Sirvan County (33°36′0″ N, 46°40′0″ E), Ilam Province, Iran. The physical and chemical properties of the experimental soil are presented in Table 1, while the rainfall pattern and the average monthly minimum and maximum temperatures are shown in Table 2. The wheat cultivar used was the durum wheat cultivar 'Saji,' a facultative type well adapted to rainfed conditions. Depending on environmental factors, this cultivar has a potential grain yield ranging from 2214 to over 3691 kg ha^{-1} with an average grain protein content of 13% (Mohammadi et al., 2010). The 1000-grain weight of this cultivar ranges from 33 g (Naseri et al., 2022) to 42 g (Zarea, 2023), depending on the rainfall pattern in Ilam Province. The experiment was arranged in a factorial design (4 × 2) based on a randomized complete block design (RCBD) with three replications. The first factor was the foliar application of urea (46% nitrogen) at four concentrations: 0%, 9.2%, 13.8%, and 18.4%. The second factor was the exogenous application of 6-BAP, consisting of either distilled water (control) or 6-BAP (purity ≥ 98%; Merck). Wheat was sown on 31 November 2022, and foliar treatments were applied on 14 May 2023. Each experimental plot measured 1 m × 3 m. Before sowing, chemical fertilizers were applied at rates of 150 kg ha^{-1} urea as the nitrogen source and 100 kg ha^{-1} triple superphosphate as the phosphorus source, incorporated into the soil prior to seeding. Surface irrigation was applied twice, once at sowing and again during stem elongation, while no irrigation was provided from flowering until harvest. Weed control was achieved using locally adopted herbicides (Granstar + Apiros).

Table 1. Physical and chemical properties of the soil prior to experiment.

ST	EC (dS/m)	pH	OC (%)	N (%)	K (mg kg^{-1})	P (mg kg^{-1})
Clay loam	2.9	7.2	0.77	0.07	221	19

ST, soil texture; pH, soil potential hydrogen; OC, organic carbon; N, nitrogen; K, potassium; P, phosphorus

Urea was foliarly applied at four concentrations: 0%, 2%, 3%, and 4% (w/v). 6-BAP was exogenously applied at two concentrations: 0 and 10 mg L^{-1}, following the method described by Zheng et al. (2016). A 0.02% Tween-20 solution was used as a surfactant, while control treatments received distilled water containing 0.2% Tween-20. All foliar treatments were applied using a backpack sprayer during the evening at the end of flowering (Zadoks growth stage 69; Zadoks et al., 1974). Plants were sprayed with 1000 L ha^{-1} of urea and/or 6-BAP solution, a volume sufficient to ensure full wetting of the wheat spikes and leaf surfaces. Foliar urea treatments were applied at equivalent rates of 0 (U_0), 9.2 (U_2%), 13.8 (U_3%), and 18.4 (U_4%) kg N ha^{-1}. Foliar cytokinin (6-BAP) was applied at 0 and 10 g ha^{-1} using the same spray volume (1000 L ha^{-1}). For combination treatments (urea + 6-BAP), the respective concentrations of urea and 6-BAP (0 and 100 mg L^{-1}) were thoroughly mixed immediately before application. Sowing was carried out mechanically in October 2021. Each plot measured 6 m × 1.2 m, with 0.5 m between blocks and 1 m spacing between plots. To determine yield components (spike weight, grain weight per spike, number of grains per spike, and spike chaff weight), five plants were randomly selected from the innermost rows of each plot at harvest. The total spike weight was recorded, after which spikes were separated into grains and chaff to determine the number of grains per spike and the respective weights of chaff and grain. The 1000-grain weight (g) was calculated by counting all grains obtained from five spikes and then expressing the value per 1000 grains. Grain yield was determined by harvesting all plants from 1 m of the innermost section of each plot, air-drying them, and weighing the grains. Grain nitrogen content was analyzed at maturity using the Kjeldahl method (Jackson, 1969). To determine grain Zn concentration, samples were ashed at 550 °C, cooled, dissolved in nitric acid, filtered, and brought to a final volume of 50 mL. Zinc concentration was measured using an atomic absorption spectrophotometer at 546 nm. Grain phosphorus (P) content was determined using the molybdate–vanadate method with a UV–visible spectrophotometer. Statistical analyses were performed using SAS software (version 9). Treatment means were compared using the least significant difference (LSD) test at a 5% probability level. Pearson correlation analysis was conducted using SAS to assess relationships among spike weight, grain weight per spike, and spike chaff weight.

Table 2. Average monthly rainfall and average monthly maximum and minimum temperatures during the wheat growing season in 2021-22

Month	Temperature (°C)		Rainfall (mm)
	Minimum	Maximum	
November	-0.8	12.2	50.2
December	-2.9	10.8	27.4
January	-6.5	6.2	33.6
February	-11	4	26.6
March	-2.1	10.1	72
April	0.5	17.6	13.4
May	3.3	19.3	40
June	7.3	28.9	0.4
July	9.9	33.5	0

RESULTS AND DISCUSSION

Table 3 shows the summary of results pertaining to the analysis of variance for the effect of foliar urea application and exogenous application of 6-BAP on number of grain per spike, spike weight, spike chaff, total grain weight per spike, thousand grain weight, and grain yield.

Number of grain per spike

Grain number per spike was significantly influenced by foliar application of urea at the flowering growth stage (Table 3). However, the effects of 6-BAP and its interaction with urea on this trait were not significant (Table 3). Although the application of 6-BAP slightly increased the number of grains per spike, this increase was not statistically significant. The highest number of grains per spike was obtained with the application of 3% (w/v) urea, whereas a higher concentration of urea (4%, w/v) had a negative effect on grain number (Fig. 1). The final number of grains per spike is largely determined during the early stages of wheat development; however, the retention of grains and prevention of grain sterility occur after flowering. Therefore, supplying the plant with urea—a key source of nitrogen, one of the most essential nutrients for plant growth—can effectively enhance grain formation. Wu et al. (2025) reported that wheat plants receiving nitrogen application at the flag leaf stage exhibited a higher grain number per spike. The present experiment was conducted under rainfed conditions, with negligible rainfall during the grain-filling period. Lv et al. (2021) found that foliar nitrogen application at anthesis improved sink capacity and mitigated drought stress in wheat. Although chlorophyll content was not measured in the present study, Noor et al. (2023) demonstrated that nitrogen fertilizer application significantly enhanced photosynthesis in flag leaves, leading to a 12% increase in grain number per spike. Conversely, excessive nitrogen fertilization has been reported to negatively affect grain number in wheat (Noor et al., 2023; Saleem Kubar et al., 2021). While the potential number of grains (florets) is determined prior to flowering, the development of inflorescences and successful grain set are influenced by post-anthesis environmental conditions. In this study, foliar urea was applied during the anthesis stage, suggesting that the observed variation in grain number may be attributed to improved physiological conditions induced by nitrogen application.

Grain weight per spike and 1000-grain weight

Total grain weight per spike was significantly influenced by foliar-applied urea, exogenous 6-BAP, and their interaction (Table 3). Similarly, both foliar urea and exogenous 6-BAP had significant effects on 1000-grain weight, although their interaction was not significant for this trait (Table 3). Compared with the control treatment, exogenous application of 6-BAP increased grain weight per spike by up to 16.6%. In the absence of 6-BAP application, the highest grain weight per spike was observed with the second and third levels of urea application (Fig. 2). However, when 6-BAP was applied, it enhanced the positive effect of foliar urea, resulting in the maximum grain weight per spike (1.77 g) in plants treated with 3% (w/v) urea plus exogenous 6-BAP (Fig. 2). The highest 1000-grain weight (47.8 g) was also obtained from the 3% (w/v) urea treatment (Fig. 3). Cytokinins regulate numerous aspects of plant growth and development. They are known to promote cell division, delay leaf senescence, and influence assimilate partitioning. Increasing endogenous cytokinin levels during the reproductive stages of wheat can significantly affect grain filling and final grain weight (Zarea, 2025a). Although the present study did not investigate the effect of 6-BAP on dry matter translocation to the grains, Luo et al. (2018) reported that exogenous application of 6-BAP enhanced wheat grain weight by promoting the transport of dry matter to the developing grains. Based on this evidence, it can be postulated that the applied 6-BAP in this study may have facilitated assimilate transport, promoted grain cell division, and delayed leaf senescence, thereby improving grain weight. Foliar urea application also significantly increased grain weight, consistent with the findings of Luo et al. (2018), who reported that foliar nitrogen application improved wheat grain weight. Previous studies have shown that nitrogen deficiency induces premature leaf senescence (Buchanan-Wollaston et al., 2003), whereas adequate nitrogen supply delays leaf senescence (Martre et al., 2006) and the onset of flag leaf senescence (Luo et al., 2018). The positive interaction observed between 6-BAP and nitrogen in the present study suggests a synergistic effect in enhancing grain weight per spike. In this experiment, plants treated with a 3% urea foliar spray exhibited the highest grain weight per spike and 1000-grain weight, while the highest urea level (4%) significantly reduced these traits. The positive influence of nitrogen fertilization on grain weight has also been reported by Arabi and Jawhar (2002). Conversely, excessive nitrogen application has been shown to have detrimental effects on grain filling. Liu et al. (2021) found a negative correlation between high nitrogen application and sucrose transport and starch accumulation in wheat grains. Similarly, Zhang et al. (2020) reported that although nitrogen fertilization significantly enhanced flag leaf photosynthesis, grain-filling capacity, and water use efficiency, higher nitrogen levels ultimately reduced wheat yield.

Spike and spike chaff weights

Analysis of Variance ANOVA results (Table 3) showed the significant effects of the main factors, foliar urea and exogenous 6-BAP, as well as their interaction on spike weight. Spike chaff was not affected by either the main treatment or their interaction, while spike weight was significantly affected.

Table 3. Summary of the statistical analysis of data for grain yield and yield component, total spike weight, and total grain weight per spike

Sources of variance	df	Mean square value					
		No. of grain per spike	Grain weight per spike	1000-Grain weight	Spike chaff weight	Spike weight	Grain yield
Block	2	2.73ns	0.04*	36.9*	0.13*	0.32**	0.05**
Urea	3	7.05*	0.07**	24.5*	0.01ns	0.11**	0.08**
6-BAP	1	4.69ns	0.13**	61.1**	0.06ns	0.38**	0.23**
Urea × 6-BAP	3	1.03ns	0.03*	10.3ns	0.03ns	0.07*	0.029*
Error	14	1.56	0.009	6.1	0.032	0.021	0.008
C.V.		3.45	6.53	6.13	26.91	6.95	4.95

df, Degrees of freedom; ns = non-significant at 0.05 probable level; ** and * = F-test significant at 1% and 5% levels, respectively; C.V., Coefficient of Variation.

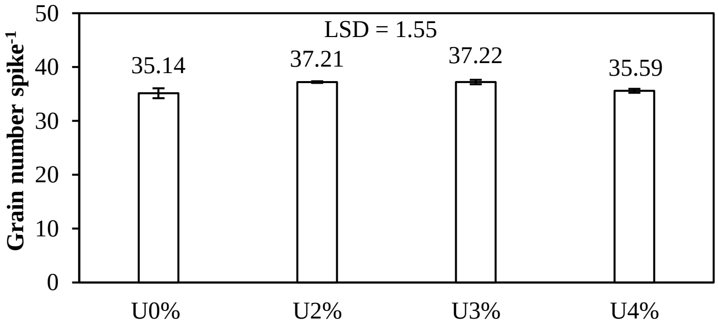

Fig. 1. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on number of grain per spike in durum wheat. Treatment code: U1%, U2%, U3%, and U4% = foliar applied urea at 0%, 2%, 3%, and 4% (w/v), respectively. Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

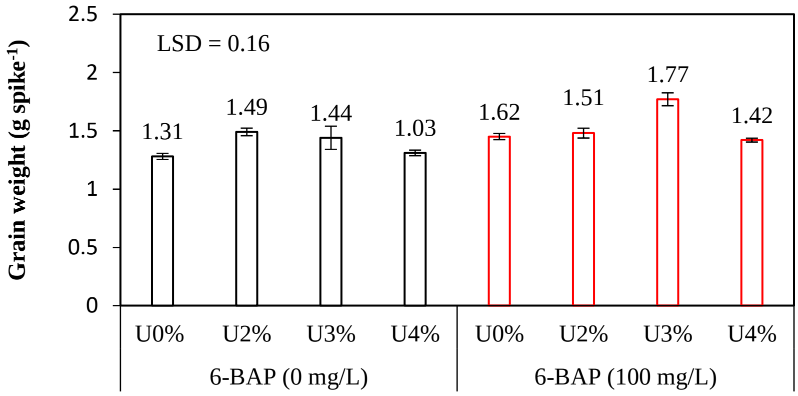

Fig. 2. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on grain weight per spike in durum wheat. Treatment code: U1%, U2%, U3%, and U4% = foliar applied urea at 0%, 2%, 3%, and 4% (w/v), respectively; Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

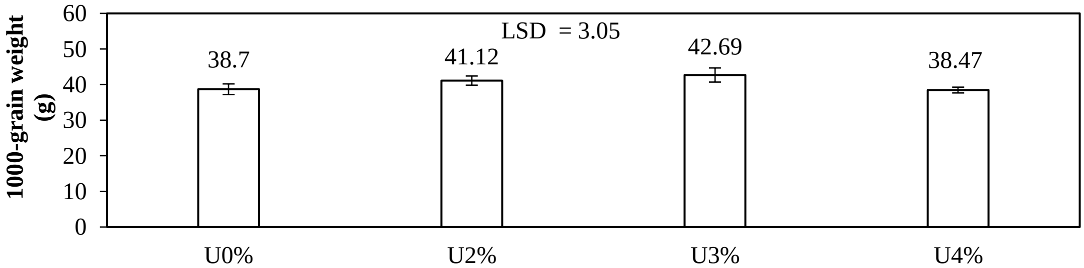

Fig. 3. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on 1000 grain in durum wheat. Treatment code: U1%, U2%, U3%, and U4% = foliar applied urea at 0%, 2%, 3%, and 4% (w/v), respectively. Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

Spike weight was significantly affected by foliar urea, exogenous 6-BAP, and their interaction (Table 3). Exogenous 6-BAP enhanced the positive effect of foliar urea, particularly at the third level of urea application (Fig. 4). As shown in Fig. 4, the highest spike weight was obtained with the 3% urea treatment in combination with

6-BAP, followed by 2% urea plus 6-BAP. In contrast, foliar application of higher urea concentration (4%) negatively affected spike weight, reducing it to a level even lower than that of the control. The application of 6-BAP alone significantly increased spike weight by 14.9% compared with the control treatment. Variations in spike weight can result from changes in either spike chaff weight and/or grain weight, as grain weight depends on both the total number of grains per spike and individual grain weight. In the present study, the treatments did not significantly affect spike chaff weight. The results further indicated that grain number per spike did not respond significantly to 6-BAP application but showed a significant response to foliar urea. Both grain number and grain weight increased significantly with urea application. A strong positive Pearson correlation was observed between grain weight and spike weight (R^2 = 0.74, P < 0.01), while the correlation between spike chaff and spike weight was moderate (R^2 = 0.64, P < 0.01). The correlation between grain number and spike weight was weak (R^2 = 0.11, P < 0.5). Therefore, the observed increase in spike weight can be primarily attributed to the enhancements in grain weight rather than to the spike chaff or grain number.

Grain yield

ANOVA for the effect of foliar urea and exogenous 6-BAP on grain yield is presented in Table 3. As shown in Table 3, the main effects of foliar urea and 6-BAP, as well as their interaction (urea × 6-BAP), significantly influenced grain yield. The interaction between foliar urea and 6-BAP is illustrated in Fig. 5. Exogenous 6-BAP application significantly increased yield by up to 10.7% compared with the control. The combined foliar application of 3% (w/v) urea and 10 mg L^{-1} 6-BAP produced the highest grain yield (2180 kg ha^{-1}) among all treatments (Fig. 5). Grain yield in wheat is determined by several yield components, including grain number per spike, grain weight, and spike number per plant. In the present study, treatments were applied at the flowering stage, followed by a three-week period of drought stress. As most tillers in wheat are formed before the onset of stem elongation, the treatments had no significant effect on tiller number per plant. The number of grains per spike was significantly affected by urea application but not by 6-BAP, while grain weight per spike and thousand-grain weight were significantly increased by both urea and 6-BAP. In addition to leaves, other photosynthetically active parts of wheat such as the stem and spike play important roles in grain filling (Aschan and Pfanz, 2003). Several studies have confirmed the contribution of the spike and stem to wheat grain yield (Li et al., 2017; Kong et al., 2016). Depending on variety and environmental conditions, the spike can contribute between 10% and 59% to total grain filling (Kriedemann et al., 1966), while the leaves contribute approximately 9–12% (Wang et al., 2001). Saleem Kubar et al. (2021) reported that nitrogen fertilizer application significantly enhances the photosynthetic rate and chlorophyll content in wheat, and that split nitrogen application further improves photosynthetic capacity (Hamani et al., 2022), emphasizing the role of nitrogen in photosynthetic performance. Similarly, Noor et al. (2023) reported that nitrogen application improves photosynthetic productivity and delays leaf senescence in wheat. It is therefore postulated that foliar urea application, by improving photosynthetic performance and delaying leaf senescence, could enhance grain yield under drought stress. In the present study, exogenous 6-BAP significantly increased grain weight but did not significantly affect grain number per spike, although a slight increase was observed. The positive effect of 6-BAP on grain yield may thus be attributed to its role in enhancing grain filling and grain-filling capacity. It has been reported that drought stress occurring during anthesis and grain-filling stages can drastically reduce wheat yield (Zhang et al., 2017). During the present experiment, rainfall totaled 40 mm from spike emergence to the late grain-filling period, indicating that plants likely experienced drought stress, particularly during grain filling. Previous studies have shown that plants under water deficit often exhibit nitrogen deficiency (Alam et al., 2020; Nazar et al., 2020). Nitrogen plays a crucial role in conferring drought tolerance (Guo et al., 2019; Lv et al., 2021), as it helps maintain normal physiological functions and enhances reactive oxygen species scavenging (Guo et al., 2019), aiding plants in coping with water deficit. Since grain filling is a nutrient transport process highly sensitive to soil water content (Chu et al., 2015), nitrogen application under limited soil moisture can support grain filling and improve yield.

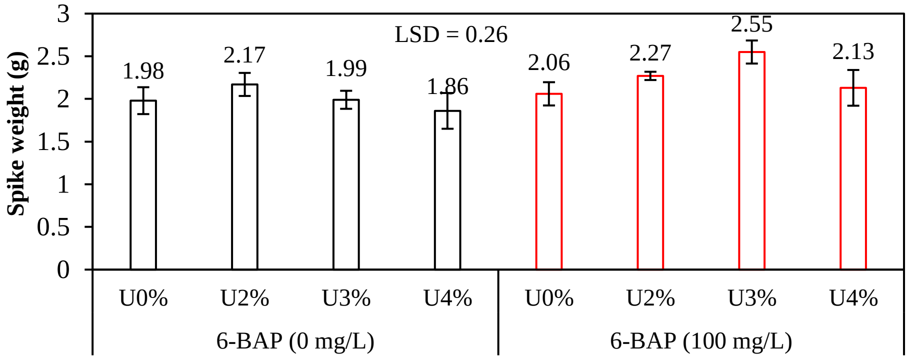

Fig. 4. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on spike weight in durum wheat. Treatment code: U1%, U2%, U3%, and U4% = foliar applied urea at 0%, 2%, 3%, and 4% (w/v), respectively. Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

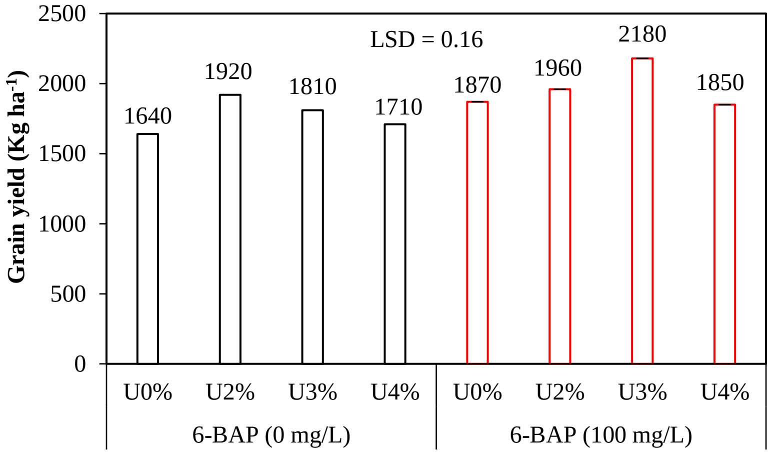

Fig. 5. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on rain yield in durum wheat. Treatment code: U1%, U2%, U3%, and U4% = foliar applied urea at 0%, 2%, 3%, and 4% (w/v), respectively; Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

Nutrient content of grains

In the present study, foliar application of urea significantly increased N and Zn contents in wheat grains, but had no significant effect on phosphorus (P) accumulation (Table 4). Exogenous application of 6-BAP had no significant effect on grain N, P, or Zn contents (Table 4). The highest grain N uptake was recorded at the 4% urea application level (Fig. 6). However, foliar application of 4% urea significantly reduced Zn accumulation in the grain (Fig. 7). Wheat absorbs only a small amount of nitrogen during grain filling, with most of the N (approximately 60–90%) being remobilized from source organs such as leaves and stems (Kong et al., 2016). In addition, drought stress can negatively affect nitrogen uptake by plants (Lv et al., 2021). In the present study, total rainfall during spike emergence to late grain filling was only 40 mm, suggesting that plants experienced drought stress during this critical stage. Previous evidence indicates that plants often exhibit nitrogen deficiency under water-deficit conditions (Alam et al., 2020; Nazar et al., 2020). It is postulated that foliar-applied urea was effectively absorbed by the leaves and subsequently translocated to the grains. Earlier studies have reported that wheat leaves are more efficient at nutrient absorption during grain filling compared with roots (Uscola et al., 2014; Visioli et al., 2018). This could explain the improved grain N and Zn contents observed with foliar urea application in the present experiment.

CONCLUSION

Wheat is one of the most important staple foods in Iran; however, its grain Zn content is relatively low (Zarea, 2025b; 2024; 2023). Therefore, strategies that can enhance both wheat grain yield and Zn concentration are of great agronomic importance. The current study demonstrated that foliar application of urea at the flowering stage is a promising approach for simultaneously improving grain yield and Zn content in wheat. Increasing urea concentration from 2% to 3% positively enhanced wheat performance, whereas a higher concentration (4%) had a detrimental effect on grain yield and Zn accumulation. Exogenous application of 6-BAP (10 mg L^{-1}) improved grain weight and grain yield but did not significantly affect grain N, P, or Zn content. The highest grain yield was obtained with the combined treatment of 6-BAP and 3% (w/v) urea. This combination can be recommended for wheat production under rainfed conditions to achieve better yield performance without compromising grain nutrient quality.

Table 4. Summary of the statistical analysis of data for grain nutrient content

Sources of variance	df	N	P	Zn
Block	2	0.007^{ns}	12480^{ns}	55.5^{ns}
Urea	3	0.010^{*}	35867^{ns}	71.4^{*}
6-BAP	1	0.003^{ns}	26347^{ns}	31.7^{ns}
Urea × 6-BAP	3	0.0007^{ns}	25070^{ns}	18.9^{ns}
Error	14	0.003	69626	22.2
C.V.		21.3	3.7	10.7

df, degrees of freedom; ns = non-significant at 0.05 probable level; ** and * = F-test significant at 1% and 5% levels, respectively; C.V., Coefficient of Variation; N, nitrogen; P, phosphorus; Zn, zinc.

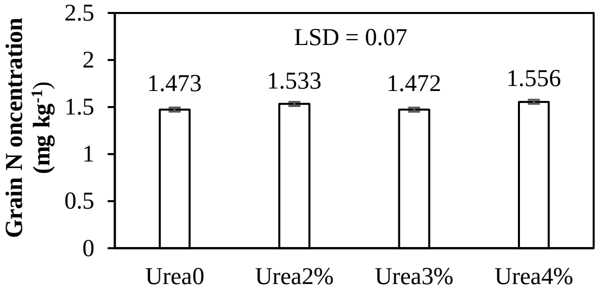

Fig. 6. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on grain nitrogen content. Urea applied at 0%, 2%, 3%, and 4% (w/v), respectively. Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

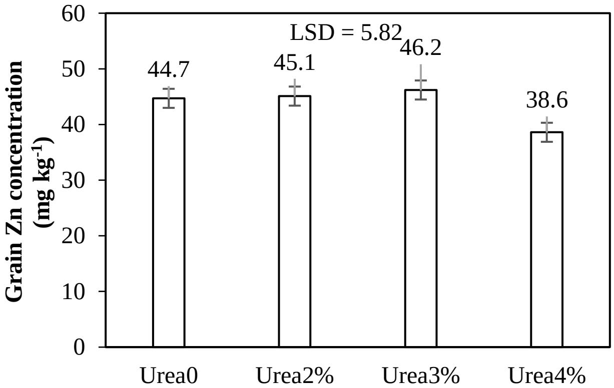

Fig. 7. Effect of foliar application of urea and 6-bezylaminopurine, given at the flowering growth stage, on grain Zn content. Treatment code: U1%, U2%, U3%, and U4% = foliar applied urea at 0%, 2%, 3%, and 4% (w/v), respectively. Values given on the bars are the mean ± standard error; LSD, Least Significant Difference.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Mohammad Javad Zarea; Methodology: Hossein Alihoseini; Software: Mohammad Javad Zarea; Validation: Hossein Alihoseini and Mohammad Javad Zarea; Formal analysis: Mohammad Javad Zarea; Investigation: Hossein Alihoseini; Resources: Hossein Alihoseini; Data curation: Hossein Alihoseini; Writing—original draft preparation: Mohammd Javad Zarea; Writing—review and editing: Mohammd Javad Zarea and Hossein Alihoseini; Visualization: Hossein Alihoseini; Supervision: Mohammd Javad Zarea.

DECLARATION OF COMPETING INTEREST

The authors declare no conflicts of interest.

ETHICAL STATEMENT

The conducted research is not related to either human or animals use. Author is aware of the content of the manuscript and consented to submit it to *Iran Agricultural Research* journal.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author on request.

ACKNOWLEDGMENTS

This article is extracted from the Ph.D. thesis of the first author at Ilam University.

REFERENCES

Alam, H., Khattak, J. Z., Ksiksi, T. S., Saleem, M. H., Fahad, S., Sohail, H., Ali, Q., Zamin, M., El-Esawi, M. A., Saud, S., Jiang, X., Alwahibi, M.S., & Alkahtani, J. (2020). Negative impact of long-term exposure of salinity and drought stress on native *Tetraena mandavillei* L. *Physiologia Plantarum*. *172*(2), 1-16. https://doi.org/10.1111/ppl.13273

Aschan, G., & Pfanz, H. (2003). Non-foliar photosynthesis: a strategy of additional carbon acquisition. *Flora*, *198*(2), 81-97. https://doi.org/10.1078/0367-2530-00080

Arabi, M. I. E., MirAli, N., & Jawhar, M. (2002). Effect of foliar and soil potassium fertilization on wheat yield and severity of *Septoria tritici* Blotch. *Australasian Plant Pathology*, *31*(4), 359-362. https://doi.org/10.1071/AP02040

Buezo, J., Esteban, R., Cornejo, A., López-Gómez, P., Marino, D., Chamizo-Ampudia, A., Gil, M. J., Martínez-Merino, V., & Moran, J. F. (2019). IAOx induces the SUR phenotype and differential signalling from IAA under different types of nitrogen nutrition in *Medicago truncatula* roots. *Plant Science*, *287*, 110176. https://doi.org/10.1016/j.plantsci.2019.110176

Bingham, I. J., & Garzon, D. C. (2023). Relative contribution of soil N availability and grain sink demand to the control of post-anthesis N uptake by field-grown spring barley. *Field Crops Research*, 292, 108829. https://doi.org/10.1016/j.fcr.2023.108829

Buchanan-Wollaston, V., Earl, S., Harrison, E. P., Mathas, E., Navabpour, S., Page, T., & Pink, D. A. (2002). The molecular analysis of leaf senescence-a genomics approach. *Plant biotechnology Journal*, *11*(1), 3-22. https://doi.org/10.1046/j.1467-7652.2003.00004.x

Borghi, B., Corbellini, M., Cattaneo, M., Fornasari, M. E., & Zucchelli, L. (1986). Modification of the sink/source relationships in bread wheat and its influence on grain yield and grain protein content. *Journal of Agronomy and Crop Science*, *157*(1), 245-254. https://doi.org/10.1111/j.1439037x.1986.tb0007x

Chu, G., Wang, Z. Q., Zhang, H., Liu, L. J., Yang, J. C., & Zhang, J. H. (2015). Alternate wetting and moderate drying increases rice yield and reduces methane emission in paddy field with wheat straw residue incorporation. *Food Energy Security*, *4*(3), 238-254. https://doi.org/10.1002/fes3.66

Delfine, S., Tognetti, R., Desiderio, E., & Alvino, A. (2005). Effect of foliar application of N and humic acids on growth and yield of durum wheat. *Agronomy for Sustainable Development*, *25*(2), 183-191.

https://doi.org/10.1051/agro:2005017

Faridnia, A., Paknejad, F., Sadeghi Shoa, M., Ilkaee, M. N., & Aghayari, F. (2024). Effect of nano micronutrients and cytokinin on wheat (*Triticum aestivum* L.) in different irrigation conditions. *Journal of Plant Nutrition*, *48*(11), 1260-1274. https://doi.org/10.1080/01904167.2024.2432501

Guo, J., Jia, Y., Chen, H., Zhang, L., Yang, J., Zhang, J., Hu, X., Ye, X., Li, Y., & Zhou, Y. (2019). Growth, photosynthesis, and nutrient uptake in wheat are affected by differences in nitrogen levels and forms and potassium supply. *Scientific Reports*, *9*(1), 1248. https://doi.org/10.1038/s41598-018-37838-3

Hamani, A. K., Abubakar, S. A., Si, Z., Kama, R., Gao, Y., & Duan, A. (2023). Suitable split nitrogen application increases grain yield and photosynthetic capacity in drip-irrigated winter wheat (*Triticum aestivum* L.) under different water regimes in the North China Plain. *Frontiers in Plant Science*, *13*, 1105006. https://doi.org/10.3389/fpls.2022.1105006

Kriedemann, P. (1966). The photosynthetic activity of the wheat ear. *Annals of Botany*, *30*(3), 349-363. https://doi.org/10.1093/oxfordjournals.aob.a084081

Kichey, T., Hirel, B., Heumez, E., Dubois, F., & Gouis, J. L. (2007). In winter wheat (*Triticum aestivum* L.), post-anthesis nitrogen uptake and remobilisation to the grain correlates with agronomic traits and nitrogen physiological markers. *Field Crops Research*, *102*(1), 22-32. https://doi.org/10.1016/j.fcr.2007.01.002

Kong, L., Xie, Y., Hu, L., Feng, B., & Li, S. (2016). Remobilization of vegetative nitrogen to developing grain in wheat (*Triticum aestivum* L.). *Feild Crops Research*, *196*(1), 134-144. https://doi.org/10.1016/j.fcr.2016.06.015

Koprna, R., de Diego, N., Dundálková, L., & Spíchal, L. (2016). Use of cytokinins as agrochemicals. *Bioorganic and Medicinal Chemistry*, *24*(3), 484-92. https://doi.org/10.1016/j.bmc.2015.12.022

Jackson M. L. (1969). *Soil chemical analysis-advanced course*. Madison: Prentice Hall Inc.

Li, Y., Li, H., Li, Y., & Zhang, S. (2017). Improving water-use efficiency by decreasing stomatal conductance and transpiration rate to maintain higher ear photosynthetic rate in drought-resistant wheat. *The Crop Journal*, *5*(3), 231-239. https://doi.org/10.1016/j.cj.2017.01.001

Liu, Y., Liao, Y., & Liu, W. (2021). High nitrogen application rate and planting density reduce wheat grain yield by reducing filling rate of inferior grain in middle spikelets. *The Crop Journal*, *9* (2), 412-426. https://doi.org/10.1016/j.cj.2020.06.013

Luo, Y., Tang, Y., Zhang, X., Li, W., Yonglan, C., Pang, D., Xu, X., Li, Y., & Wang, Z. (2018). Interactions between cytokinin and nitrogen contribute to grain mass in wheat cultivars by regulating the flag leaf senescence process. *The Crop Journal*, *6*(5), 538-551. https://doi.org/10.1016/j.cj.2018.05.008

Lv, X., Ding, Y., Long, M., Liang, W., Gu, X., Liu, Y., & Wen, X. (2021). Effect of foliar application of various nitrogen forms on starch accumulation and grain filling of wheat (*Triticum aestivum* L.) under Drought Stress. *Frontiers in Plant Science*, *12*, 645379. https://doi.org/10.3389/fpls.2021.645379

Lyu, X., Liu, Y., Li, N., Ku, L., Hou, Y., & Wen, X. (2021). Foliar applications of various nitrogen (N) forms to winter wheat affect grain protein accumulation and quality via N metabolism and remobilization. *The Crop Journal*, *10*(4), 1165-1177. https://doi.org/10.1016/j.cj.2021.10.009

Martre, P., Jamieson, P. D., Semenov, M. A., Zyskowski, R. F., Porter, J. R., & Triboi, E. (2006). Modelling protein content and composition in relation to crop nitrogen dynamics for wheat. *European Journal of Agronomy*, *25*(2), 138-154. https://doi.org/10.1016/j.eja.2006.04.007

Mohammadi, R., Aghaee Sarbarze, M., Haghparast, R., Armion, M., SadeghzadehAhari, D., & Roustaii, M. (2010). Saji, a new durum wheat cultivar adapted to rainfed and supplementary irrigation conditions of moderate cold and moderate warm areas of Iran. *Seed and Plant Journal*, *26*(4), 561-565. https://doi.org/10.22092/spij.2017.111043

Nagar, S., Ramakrishnan, B. S., Singh, B. J., Singh, B. J., Dhakar, B. R., Umesh, B. D., & Arora, A. K. (2015). Cytokinin enhanced biomass and yield in wheat by improving N-metabolism under water limited environment. *Indian Journal of Plant Physiology*, *20*(1), 31-38. https://doi.org/10.1007/s40502-014-0134-3

Naseri, R., Barary, M., Zarea, M. J., Khavazi, K., & Tahmasebi, Z. (2022). Effect of phosphate solubilizing bacteria and mycorrhizal fungi on agronomic important traits in two wheat (*Triticum aestivum* L.; *Triticum turgidum* var. durum) cultivars under dryland conditions. *Journal of Agroecology*, *14*(1), 19-33 (In Persian). https://doi.org/10.22067/jag.v11i4.51317

Nazar, Z., Akram, N. A., Saleem, M. H., Ashraf, M., Ahmed, S., Ali, S., Abdullah Alsahli, A., & Alyemeni, M. N. (2020). Glycinebetaine-induced alteration in gaseous exchange capacity and osmoprotective phenomena in safflower (*Carthamus tinctorius* L.) under water deficit conditions. *Sustainability*, *12*(24), 10649. https://doi.org/10.3390/su122410649

Noor, H., Yan, Z., Sun, P., Zhang, L., Ding, P., Li, L., Ren, A., Sun, M., & Gao, Z. (2023). Effects of nitrogen on photosynthetic productivity and yield quality of wheat (*Triticum aestivum* L.). *Agronomy*, *13*(6), 1448. https://doi.org/10.3390/agronomy13061448

Prasad, R. (2022). Cytokinin and its key role to enrich the plant nutrients and growth under adverse conditions-An update. *Frontiers in Genetics*, *13*, 883924. https://doi.org/10.3389/fgene.2022.883924

Ru, C., Hu, X., Wang, W., & Yan, H. (2024). Impact of nitrogen on photosynthesis, remobilization, yield, and efficiency in winter wheat under heat and drought stress. *Agricultural Water Management*, *302*, 109013. https://doi.org/10.1016/j.agwat.2024.109013

Saleem Kubar, M., Feng, M., Sayed, S. M., Hussain Shar, A., Ali Rind, N., Ullah, H., Ali Kalhoro, S., Xie, Y., Yang, C., Yang, W., Ali Kalhoro, F., Gašparovič, K., Barboričová, M., Brestič, M., El Askary, A., & El-Sharnouby, M. E. (2021). Agronomical traits associated with yield and yield components of winter wheat as affected by nitrogen managements. *Saudi Journal of Biological Sciences*, *28*(9), 4852-4858. https://doi.org/10.1016/j.sjbs.2021.07.027

Sarandón, S. J., & Gianibelli, M. C. (1992). Effect of foliar sprayings of urea during or after anthesis on dry matter and nitrogen accumulation in the grain of two wheat cultivars of *T. aestivum* L. *Fertilizer Research*, *31*(1), 79-84. https://doi.org/10.1007/BF01064230

Taulemesse, F., Le Gouis, J., Gouache, D., Gibon, Y., & Allard, V. (2015). Post-flowering nitrate uptake in wheat is controlled by N status at flowering, with a putative major role of root nitrate transporter NRT2.1. *PLoS ONE*, *10*(3), e0120291. https://doi.org/10.1371/journal.pone.0120291

Uscola, M., Villar-Salvador, P., Oliet, J., & Warren, C. R. (2014). Foliar absorption and root translocation of nitrogen from different chemical forms in seedlings of two Mediterranean trees. *Environmental and Experimental Botany*, *104*(1), 34-43. https://doi.org/10.1016/j.envexpbot.2014.03.004

Visioli, G., Bonas, U., Dal Cortivo, C., Pasini, G., Marmiroli, N., Mosca, G., & Vamerali, T. (2018). Variations in yield and gluten proteins in durum wheat varieties under late-season foliar versus soil application of nitrogen fertilizer in a northern Mediterranean environment. *Journal of the Science of Food and Agriculture*, *98*(6), 2360-2369. https://doi.org/10.1002/jsfa.8727

Wang, Y., Peng, Y., Lin, J., Wang, L., Jia, Z., & Zhang, R. (2023). Optimal nitrogen management to achieve high wheat grain yield, grain protein content, and water productivity: A meta-analysis. *Agricultural Water Management*, *290*(2), 108587. https://doi.org/10.1016/j.agwat.2023.108587

Wang, Z. M., Wei, A. L., & Zheng, D. M. (2001). Photosynthetic characteristics of non-leaf organs of winter wheat cultivars differing in ear type and their relationship with grain mass per ear. *Photosynthetica*, *39*(2), 239-244. https://doi.org/10.1023/A:1013743523029

Woolfolk, C. W., Raun, W. R., Johnson, G. V., Thomason, W. E., Mullen, R. W., Wynn, K. J., & Freeman, K. W. (2002). Influence of late-season foliar nitrogen applications on yield and grain nitrogen in winter wheat. *Agronomy Journal*, *94*(3), 429-434. https://doi.org/10.2134/agronj2002.4290

Wu, W., Wang, Y., Xu, H., Liu, M., & Xue, C. (2025). Enhancing wheat yield and quality through late-season foliar nitrogen application: A global meta-analysis. *Agronomy*. *15*(5), 1058. https://doi.org/10.3390/agronomy15051058

Zadok, J. C., Chang, T. T., & Konzak, C. F. (1974). A decimal code for growth stages of cereals. *Weed Research*, *14*(6), 415-421. https://doi.org/10.1111/j.1365-3180.1974.tb01084.x

Zarea, M. J. (2023). Effect of foliar application of Zinc and exogenous application of proline on yield and grain Zn and P content in a wheat durum cultivar Saji under drought stress condition. *Cereal Biotechnology and Biochemistry*, *2*(3), 269-287. (In Persian) https://doi.org/10.22126/cbb.2024.9987.1061

Zarea, M. J. (2024). Foliar application of *Azospirillum brasilense*, salicylic acid and zinc on wheat Performance under rain-fed condition. *Cereal Research Communications*, *53*(2), 1073-1090. https://doi.org/10.1007/s42976-024-00570-y

Zarea, M. J. (2025a). Effect of foliar application of *Azospirillum brasilense* and zinc sulfate on the grain-filling process of rainfed wheat. *Iran Agricultural Research*, *43*(2), 1-9. https://doi.org/10.22099/iar.2024.50169.1595

Zarea, M. J. (2025b). The regulatory roles of phytohormones in the wheat grain-filling process. *Plant Growth Regulation*, *44*(6), 2609-2626. https://doi.org/10.1007/s00344-024-11587-2.

Zarea, M. J., & Karimi, N. (2023). Grain yield and quality of wheat are improved through post-flowering foliar application of zinc and 6-benzylaminopurine under water deficit condition. *Frontiers in Plant Science*, *13*, 1068649. https://doi.org/10.3389/fpls.2022.1068649

Zhang, J., Yang, J., An, P., Ren, W., Pan, Z., Dong, Z., Han, G., Pan, Y., Pan, S., & Tian, H. (2017). Enhancing soil drought induced by climate change and agricultural practices: Observational and experimental evidence from the semiarid area of northern China. *Agricultural and Forest Meteorology*, *243*(1), 74-83. https://doi.org/10.1016/j.agrformet.2017.05.008

Zhang, Z., Zhang, Y., Shi, Y., & Yu, Z. (2020). Optimized split nitrogen fertilizer increase photosynthesis, grain yield, nitrogen use efficiency and water use efficiency under water-saving irrigation. *Scientific Reports*, *10*, 20310. https://doi.org/10.1038/s41598-020-75388-9

Zheng, C., Zhu, Y., Wang, C., & Guo, T. (2016). Wheat grain yield increase in response to pre-anthesis foliar application of 6-Benzylaminopurine is dependent on floret Development. *PLoS ONE*, *11*(6), e0156627. https://doi.org/10.1371/journal.pone.0156627