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Effect of Foliar Application of Zinc on Leaf Expanse, Dry Matter Accumulation and Its Correlation with Grain Yield in Wheat

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Wheat (*Triticum aestivum* L.) is a vital staple crop essential for global food security, especially in developing countries. This study investigates the impact of foliar zinc (Zn) application on leaf expanse, dry matter accumulation, and their correlation with grain yield in wheat. Conducted over two cropping seasons (2019-20 and 2020-21) at the N.E. Borlaug Crop Research Centre, GBPUA&T, Pantnagar, India, the experiment used a split plot design with five Zn sulphate concentrations (0, 0.25, 0.5, 0.75, and 1% $ZnSO_4 \cdot 7H_2O$) and three spray frequencies (one, two, and three sprays). Results indicated that foliar Zn application significantly increased the Leaf Area Index (LAI), flag leaf length, and width. The highest LAI (4.69) was achieved with three sprays of 1702.5 ppm Zn, a 77% increase over the control. Similarly, flag leaf length and width increased by up to 42.8% and 41.5%, respectively. Zn application also enhanced dry matter accumulation, with the highest increase (50%) observed with two sprays of 2270 ppm Zn at maximum tillering. At the flowering stage, dry matter increased significantly, with the highest observed at one spray of 2270 ppm Zn. Grain yield improved significantly with Zn application, peaking at a 16.7% increase with 1702.5 ppm Zn. A positive correlation was found between Zn concentration, LAI, flag leaf dimensions, dry matter accumulation, and grain yield, indicating that foliar Zn application not only enhances grain yield directly but also improves overall plant growth characteristics. Future research should explore the long-term effects of foliar Zn application on soil health and nutrient cycling.

Keywords: Wheat; nutrient cycling; agronomic biofortification; leaf surface area; zinc sulphate.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important staple crops worldwide, playing a critical role in global food security. It is a major source of calories and protein for a significant portion of the world's population, particularly in developing countries, where it fulfills approximately 60% of daily caloric requirements. In India, for instance, wheat accounts for 13.53% of global wheat production, making the country the second-largest wheat producer in the world [1,2]. Given its importance, optimizing wheat growth and yield is essential to meet the increasing food demand driven by population growth and changing dietary patterns. Zinc (Zn) is an essential micronutrient necessary for the proper growth and development of plants. It is a vital component of various physiological and biochemical processes, influencing numerous aspects of plant metabolism. Zn is integral to the synthesis of auxin, a key plant hormone that regulates growth and development, including cell elongation and division. Additionally, Zn functions as a cofactor for many enzymes involved in critical processes such as protein synthesis, carbohydrate metabolism, and chlorophyll production [3,4].

Despite its importance, Zn deficiency is a widespread issue that severely affects crop productivity and food security globally [5]. Zn deficiency manifests in plants as stunted growth, chlorosis (yellowing of leaves), and reduced leaf size, ultimately leading to lower yields. In wheat, Zn deficiency is particularly problematic as it directly impacts both grain quality and quantity. Factors such as high soil pH, low organic matter content, and imbalanced fertilizer use exacerbate Zn deficiency by reducing its bioavailability in the soil [6]. Foliar application is a technique where nutrients are applied directly to the leaves of plants, allowing for rapid absorption through the cuticle and stomata. This method is especially effective for correcting micronutrient deficiencies, such as Zn, because it bypasses soil-related issues that can limit nutrient availability. Foliar Zn application ensures that Zn is delivered directly to the site of action, leading to quicker and more efficient uptake compared to soil application [7].

Grain yield is the ultimate measure of a crop's productivity and is influenced by several components. For example, leaf expanse, or leaf area, is a critical parameter that directly influences a plant's ability to capture sunlight and perform photosynthesis. A larger leaf area allows for greater light interception, leading to increased photosynthetic activity and higher biomass production which is a direct indicator of the plant's growth and productivity. Similarly, dry matter accumulation refers to the total biomass produced by a plant, excluding water content. It reflects the plant's ability to assimilate carbon and other essential nutrients, translating into growth and yield. In wheat, dry matter accumulation during key growth stages such as tillering, booting, heading, and grain filling has a significant impact on final yield. Numerous studies have demonstrated the effectiveness of foliar Zn application in improving plant growth, yield, and nutrient content [8,9,10,6].

The benefits of foliar Zn application include increased leaf chlorophyll content, enhanced photosynthetic efficiency, and improved overall plant health. These improvements contribute to greater dry matter accumulation and higher grain yields. However, the effectiveness of foliar Zn application can vary depending on factors such as the concentration of the Zn solution, the timing of application, and environmental conditions [11,12,13]. Understanding the relationship between foliar Zn application, leaf area expansion, dry matter accumulation, and grain yield is essential for developing effective management practices to enhance wheat productivity. By optimizing Zn nutrition through foliar application, it is possible to improve both the quantity and quality of wheat grains. The primary objective of this study is to investigate the effect of foliar Zn application on leaf expanse, dry matter accumulation, and their correlation with grain yield in wheat.

2. MATERIALS AND METHODS

The field study was carried out at the N.E. Borlaug Crop Research Centre, which is part of Govind Ballabh Pant University of Agriculture and Technology, located in Pantnagar, Uttarakhand, India. The study was conducted specifically during the wheat cropping seasons of 2019-20 and 2020-21. Each year, the wheat variety PBW343 was planted in early November and harvested in early April. The meteorological data for the duration of the experiment is presented in Fig. 1. The experiment employed a split plot design, with the main plot treatments consisting of five different concentrations of Zn

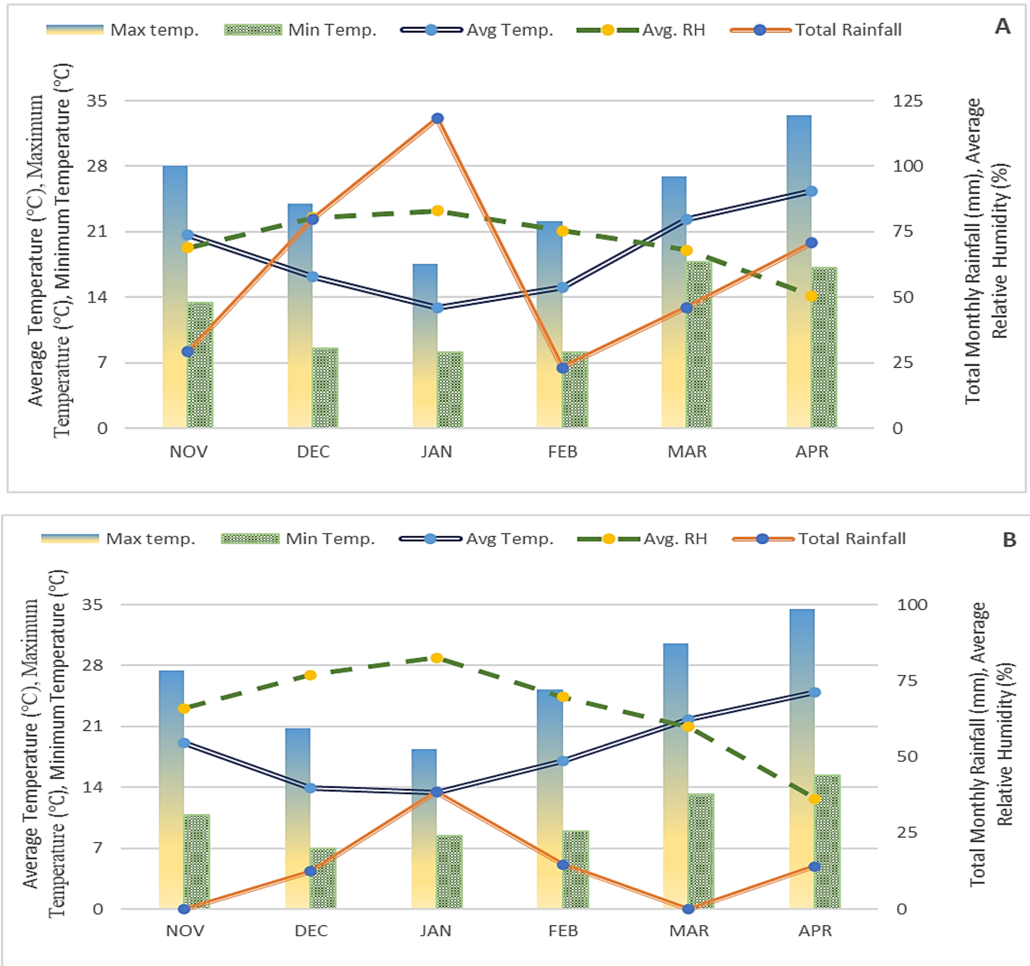

Fig. 1. Metrological data for the two seasons; 2019-20 (A) and 2020-21 (B)
(Source- Agro-meteorological observatory, N.E.B. Crop Research Centre, GBPUA&T, Pantnagar, Uttarakhand, India)

sulphate viz. 0, 0.25, 0.5, 0.75 and 1% $ZnSO_4 \cdot 7H_2O$ corresponding to 0, 567.5, 1135, 1702.5 and 2270 ppm Zn respectively. The subplot treatments involved three levels of spray frequencies: S1 (one spray at 30 days after emergence), S2 (two sprays, one at 30 days and another at 45 days after emergence), and S3 (three sprays, one at 30 days, another at 45 days, and a third at 60 days after emergence). The experiment consisted of four replications, with each treatment occupying a plot measuring 5m × 3m. The prescribed set of techniques for wheat cultivation were adhered to, and a portable sprayer was utilized for the spraying of Zn sulphate on the leaves. At the time of harvesting, measurements were taken for grain yield, biological yield, and other variables associated with yield. Statistical analyses were conducted using the R statistical package (Version 4.1.2). Correlation among parameters was evaluated using linear regression models. The correlation matrices were drawn to understand the relationships between contrasting variable. The significance of the effects of the treatments and their interactions on the reported parameters was evaluated by analysis of variance (ANOVA). Standard error of means (S.Em.±) and critical difference (CD) was evaluated at 5% level of significance ($p \leq 0.05$) by following standard statistical procedure.

3. RESULTS

3.1 Expansion in Leaf Surface Area

The Leaf Area Index (LAI) increased significantly at all concentrations of Zn compared to the control (LAI of 2.78). The increase in LAI due to Zn application ranged from 20.1% at 567.5 ppm Zn (LAI-3.34) to 60.1% at 2270 ppm Zn (LAI-4.45). An increase in the number of sprays further increased LAI by 9.8% and 18.7% with two and three sprays, respectively (Fig. 2A). The highest LAI (4.69) was observed with three sprays of 1702.5 ppm Zn, 77% higher than the control. Flag leaf length, initially 16.52 cm without Zn application, also increased significantly with Zn, ranging from a 9.8% increase at 567.5 ppm Zn to a 37.1% increase at 2270 ppm Zn. More sprays led to additional increases of 3.4% and 5.7% in flag leaf length with two and three sprays, respectively. The maximum flag leaf length (23 cm) was achieved with three sprays of 1702.5 ppm Zn, a 42.8% increase over the control (Fig. 2B). Flag leaf width similarly increased significantly with Zn, ranging from a 9.4% increase at 567.5 ppm Zn to a 35.8% increase at 2270 ppm Zn. Two and three sprays resulted in further increases of 8.5% and 15.4% in flag leaf width, respectively. The maximum flag leaf width (1.5 cm) was observed with three sprays of 1702.5 ppm Zn, a 41.5% increase over the control. Significant interaction effects between Zn concentration and the number of sprays were noted across all parameters (Fig. 2C).

3.2 Dry Matter Accumulation

The application of Zn significantly increased the total aboveground dry matter at maximum tillering across all tested concentrations compared to the control, which had a dry matter of 386 g/m² (Table 1). Zn application led to increases ranging from 9.4% at 567.5 ppm Zn to 35.8% at 2270 ppm Zn. Additionally, the number of Zn sprays influenced the total aboveground dry matter, with two and three sprays resulting in increases of 8.5% and 15.4%, respectively. A significant interaction effect was noted between Zn concentrations and the stages of its application. The highest total aboveground dry matter at maximum tillering was observed with two sprays of 2270 ppm Zn, which was 50% higher than the control. Similarly, at the flowering stage, total aboveground dry matter also increased significantly at all Zn concentrations compared to the control. The increase ranged from 6.7% at 567.5 ppm Zn to 17.1% at 2270 ppm Zn. Unlike the maximum tillering stage, the increase in total dry matter at the flowering stage was minimal (<1%) with additional sprays. Nonetheless, a significant interaction effect between Zn concentration and the number of sprays was observed. The highest total aboveground dry matter at the flowering stage was achieved with one spray of 2270 ppm Zn.

3.3 Grain Yield and its Correlation with Leaf Expanse and Dry Matter Accumulation

Grain yield increased significantly at all tested concentrations of Zn compared to the control, which had a grain yield of 4.84 t/ha. Zn application resulted in increases ranging from 6.8% at 567.5 ppm Zn (5.17 t/ha) to a maximum of 16.7% at 1702.5 ppm (5.63 t/ha) Zn (Fig. 3). Neither the stages of application nor the interaction between concentration and stages of application had a significant effect on grain yield. A positive and significant correlation was observed between Zn concentration and several key parameters: leaf area index, flag leaf length and width, total aboveground dry matter at maximum tillering and flowering, and grain yield (Figs. 4 and 5).

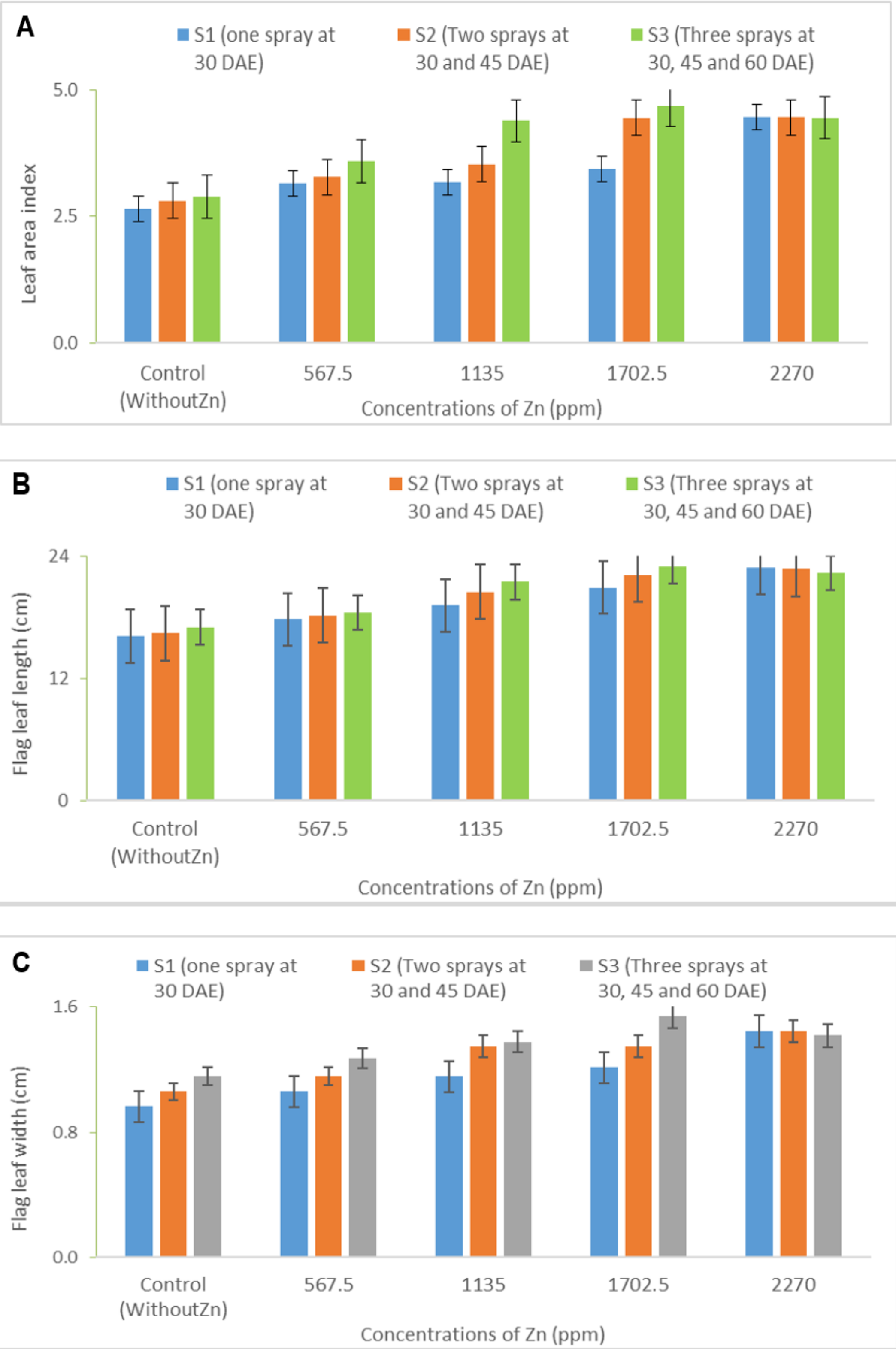

Fig. 2. Effect of different concentrations and stages of foliar application of Zn on LAI (A) flag leaf length (B) and flag leaf width (C) of wheat cultivar PBW343

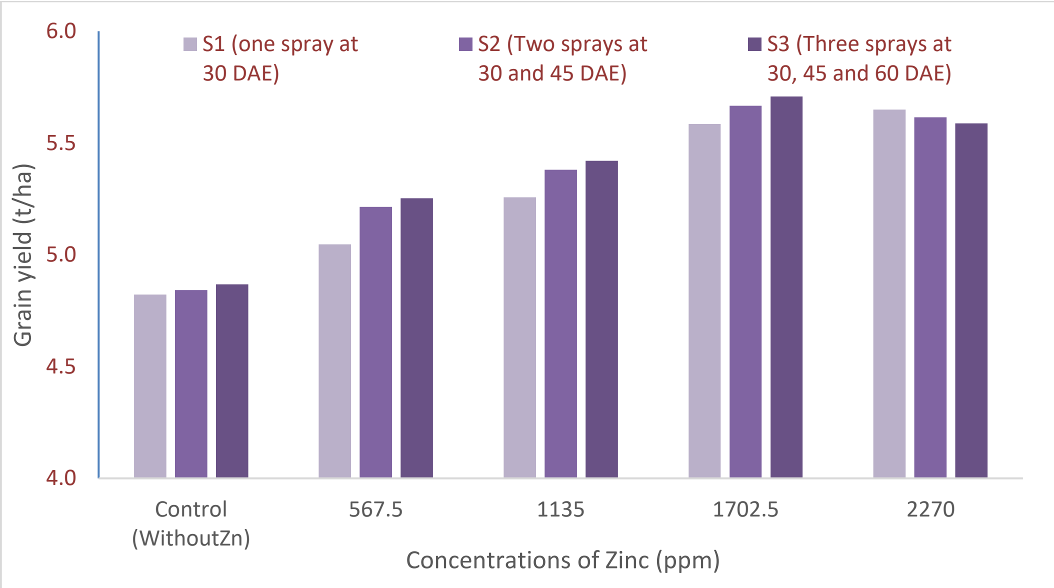

Fig. 3. Effect of different concentrations and stages of foliar application of Zn on grain yield of wheat cultivar PBW343

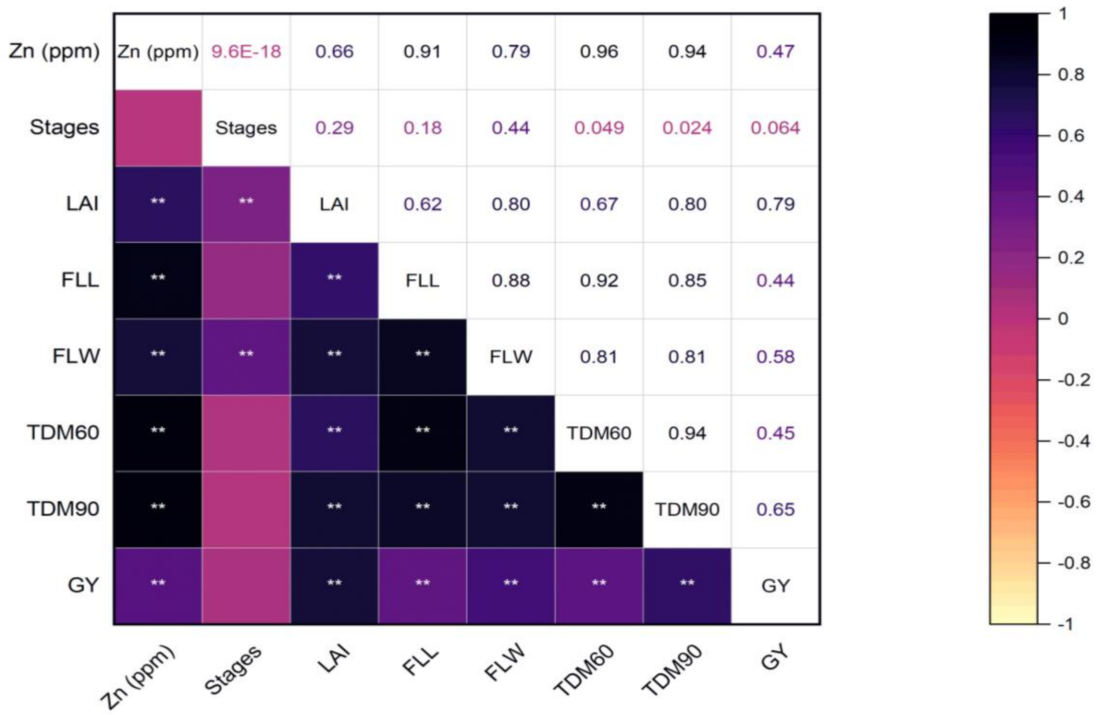

Fig. 4. Correlation matrix between different growth, yield and yield contributing factors in wheat cultivar PBW343 as affected by concentration and stages of foliar application of Zn. The color gradient on the right indicates the correlation values and the same are represented in figures in the upper half triangle of the matrix

*The asterisks within the boxes indicate the significance level: **- p<0.01, *- p<0.5. Zn (ppm) and Stages signify concentrations and stages of Zn application. Different parameters are represented in their abbreviated notations viz. Leaf area index (LAI), Flag leaf length (FLL), Flag leaf width (FLW), Total aboveground dry matter at maximum tillering (TDM60), Total aboveground dry matter at flowering (TDM90) and Grain yield (GY).*

Table 1. Effect of different concentrations and stages of Zn application on total aboveground dry matter (g/m2) of wheat cultivar PBW343 at maximum tillering and flowering stage (data are means of two growing seasons, 2019-20 and 2020-21)

Concentrations of Zn (C, in ppm)	Total aboveground dry matter Maximum Tillering (g/m^2)			Total aboveground dry matter Flowering (g/m^2)		
	S1*	**S2**	**S3**	**S1***	**S2**	**S3**
Control (No Zn)	391 ± 6.00	379 ± 10	389 ± 8	765 ± 21	753 ± 25	761 ± 22
567.5	410 ± 3.00	420 ± 2	422 ± 3	797 ± 12	818 ± 7	816 ± 8
1135.0	437 ± 5.00	441 ± 5	452 ± 5	823 ± 8	829 ± 8	831 ± 10
1702.5	453 ± 4.00	461 ± 6	457 ± 4	865 ± 12	876 ± 10	869 ± 16
2270 .0	480 ± 11.00	472 ± 7	470 ± 4	898 ± 8	887 ± 13	885 ± 15
	C	**S**	**C×S**	**C**	**S**	**C×S**
S.Em ±	1.88	0.63	3.26	2.22	0.66	3.85
C.D (P=0.05)	5.45	1.79	3.99	6.43	1.88	4.20

S1: One spray at 30 days after emergence
S2: Two sprays, one each at 30 and 45 days after emergence
S3: Three sprays, one each at 30, 45 and 60 days after emergence

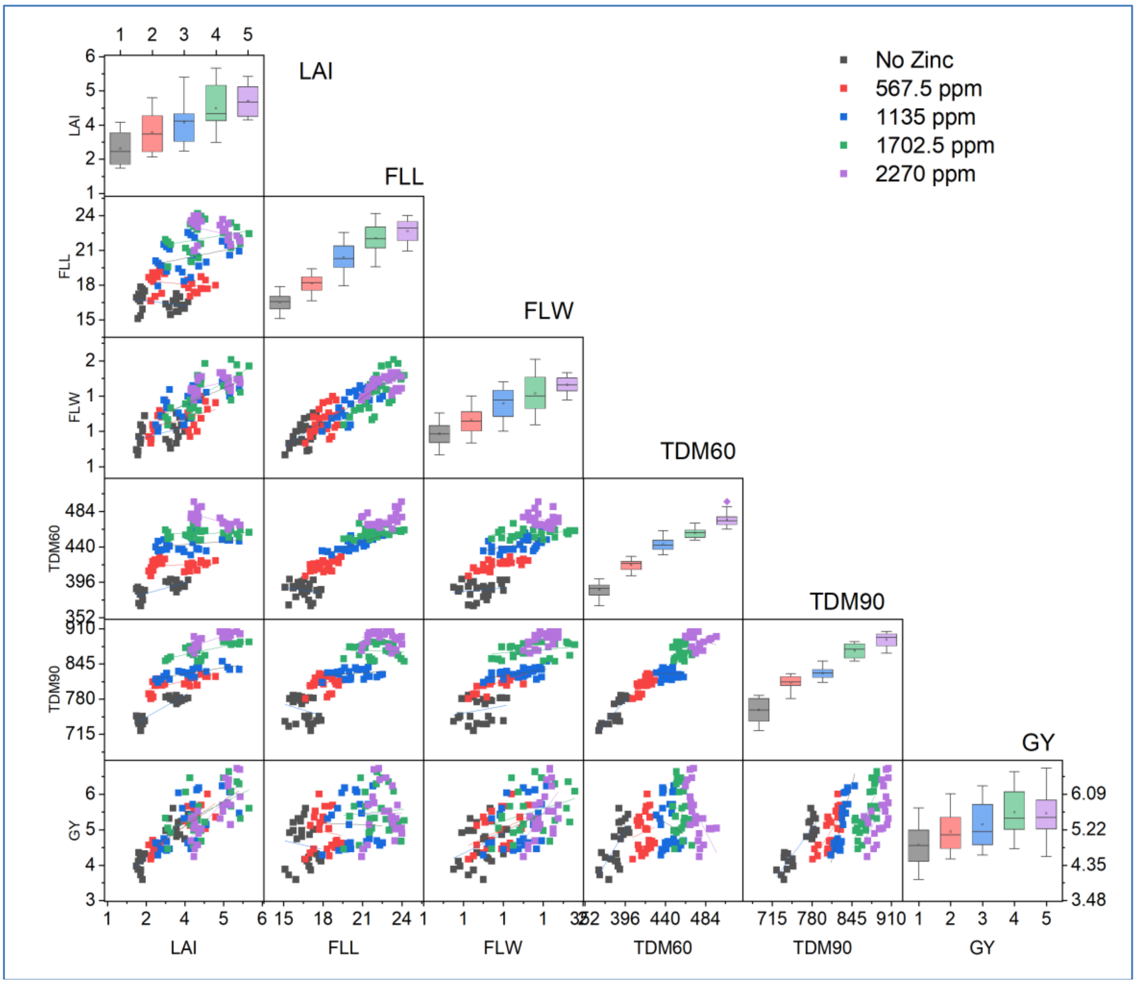

Fig. 5. Scatterplot matrix between different growth, yield and yield contributing factors in wheat cultivar PBW343 as grouped by concentrations of foliar application of Zn

Different parameters are represented in their abbreviated notations viz. Leaf area index (LAI), Flag leaf length (FLL), Flag leaf width (FLW), Total aboveground dry matter at maximum tillering (TDM60), Total aboveground dry matter at flowering (TDM90) and Grain yield (GY).

4. DISCUSSION

Leaf expanse, or leaf area, is a key determinant of a plant's photosynthetic capacity and overall growth. Larger leaf area allows for greater light interception, leading to increased photosynthetic activity and higher biomass production. In wheat, leaf area is closely related to dry matter accumulation, which is a direct indicator of the plant's growth and productivity. Increases in both LAI as well as flag leaf length and width by Zn application has been reported by Nadim et al. [7], Rawashdeh and Sala [14], Jalal et al. [13], Ramzan et al. [10]. The beneficial effects of foliar Zn application on dry matter accumulation and yield in wheat are likely mediated through enhanced physiological and biochemical processes. Zn is involved in several key metabolic pathways, including protein synthesis, carbohydrate metabolism, and chlorophyll production. Furthermore, significant correlation observed between Zn concentration and several key parameters suggests that Zn application not only enhances grain yield directly but also improves other plant growth characteristics that contribute to higher productivity (Figs. 3 & 4). Specifically, the increase in leaf area index indicates more efficient photosynthesis, while longer and wider flag leaves can enhance the plant's ability to capture sunlight and perform photosynthesis more effectively. The total aboveground dry matter at both maximum tillering and flowering stages reflects overall plant vigor and biomass accumulation, which are critical for supporting higher grain yields. These correlations highlight the multifaceted role of Zn in promoting plant health and productivity, underscoring its importance in agricultural practices aimed at optimizing crop yields. Such effects of Zn foliar application have been reported by earlier workers also [15,3,10].

5. CONCLUSION

The study demonstrated that foliar Zn application significantly increased leaf area, dry matter accumulation, and grain yield in wheat, with increases in key parameters such as leaf area index, flag leaf dimensions, and total aboveground dry matter. These enhancements are attributed to improved photosynthetic efficiency and overall plant vigor. The findings underscore Zn's vital role in promoting plant health and optimizing crop yields. Future research should explore the long-term effects of foliar Zn application under different environmental conditions and investigate the optimal combination of Zn with other micronutrients to maximize wheat productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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