Role of Integrated Nutrient Management and Agronomic Fortification of Zinc on Yield, Nutrient Uptake and Quality of Wheat

Venkatesh Paramesh 1,2,* , Shiva Dhar 1, Anchal Dass 1, Bipin Kumar 1, Amit Kumar 1, Diaa O. El-Ansary 3 and Hosam O. Elansary 4,5,*

1 Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110012, India; drsdmisra@gmail.com (S.D.); anchal_d@rediffmail.com (A.D.); bipiniari@gmail.com (B.K.); amitkumar33026@gmail.com (A.K.)
2 Natural Resource management Section, ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa 403402, India
3 Precision Agriculture Laboratory, Department of Pomology, Faculty of Agriculture (El-Shatby), Alexandria University, Alexandria 21545, Egypt; diaaagri@hotmail.com
4 Plant Production Department, College of Food and Agricultural Sciences, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia
5 Floriculture, Ornamental Horticulture, and Garden Design Department, Faculty of Agriculture (El-Shatby), Alexandria University, Alexandria 21545, Egypt
* Correspondence: parameshagron@gmail.com (V.P.); helansary@ksu.edu.sa (H.O.E.); Tel.: +966-581216322 (H.O.E.)

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Abstract: Phosphorus (P) and zinc (Zn) are essential plant nutrients, and their deficiency in soils and the antagonistic effect of P on Zn are important concerns world-over. Thus, a two-year (2012–13 to 2013–14) experimentation was carried out to assess grain yield, nutrient uptake and quality parameters of wheat by various levels of P and Zn. The results revealed that 50% recommended dose of P (RDP) through phospho-enriched compost (PEC) + 50% RDP through fertiliser and soil application of 12.5 kg ZnSO₄·7H₂O ha⁻¹ + one foliar spray of 0.5% ZnSO₄·7H₂O recorded significantly higher grain yield (4.81 and 4.61 t ha⁻¹, respectively), straw yield (7.20 and 6.92 t ha⁻¹, respectively) and protein content (11.5% and 11.3%, respectively). The concentrations of Zn in grain (35.6%) and straw (57.3%) were not affected due to organic P application but 100% P through P fertilizer reduced the Zn content in the grains. Both soil and foliar application of Zn were found to be more promising in increasing Zn and Fe concentration in grains (37.5 and 30.9 mg kg⁻¹, respectively) and straw (60.3 and 398 mg kg⁻¹, respectively). Overall, the treatment combination of 50% RDP through PEC + 50% RDP through fertiliser and soil applied 12.5 kg ZnSO₄·7H₂O ha⁻¹ + one spray of 0.5% Zn was beneficial in reducing antagonistic effect of P on Zn and increasing Zn and Fe concentration in wheat grain and, thus, could be used for improving the yield of Zn and Fe enriched wheat grains.

Keywords: nutrient uptake; phospho-enriched compost; phosphorus; wheat; zinc

1. Introduction

Phosphorus (P) is the second most important essential nutrient for crop production after nitrogen [1]. This nutrient plays various roles in the plant metabolism including a structural role in molecules, such as nucleic acids and proteins, for energy transfer, respiration, glycolysis, carbohydrate metabolism, redox reactions, enzyme activation/inactivation, membrane synthesis and stability, and in nitrogen fixation [2]. Phosphorus is a component of DNA and RNA, which carries genetic information used to
synthesize proteins. Phosphorus is essentially important to human beings also; it is involved in the growth and repair of body cells and tissues. Its deficiency in children affects normal bone and teeth development [3]. Thus, there is rising concern over widespread deficiency of P in the agricultural lands of the world. More than 50% soils have been reported to be deficient in P [4]. Application of an adequate amount of P through organic manures and chemical fertilizers sustains crop productivity and enriches the P in the soil, but fixation of P by clay minerals that are rich in acids soils, including various iron oxides and kaolinite, renders the applied P unavailable for root uptake, and ultimately leading to a very low P-use efficiency (15–20%). Soil pH values below 5.5 and between 7.5 and 8.5 limit phosphate availability to plants, due to fixation by calcium. Hence, a paramount importance is given to the efficient use of P fertiliser for sustainable crop production [5]. In India, where majority of population is vegetarian, P deficiency is a major constraint to crop production as 80% of the soils in Indian are low to medium in P availability, necessitating P additions to obtain optimum plant growth and higher productivity [6].

Zinc (Zn) deficiency is widespread in the world, particularly in the Asian and African continents and affecting both human health and crop production [7]. Wheat is more relevant to both of these concerns, as wheat is more susceptible to soil Zn deficiency and is a staple food crop for some of the Zn-deficient human population [8]. The regions with Zn-deficient soils are also regions of widespread Zn deficiency in human beings, including India, Pakistan, China, Iran and Turkey [9]. Producing staple food crop grains richer in Zn could certainly help in alleviating Zn deficiencies in both humans and animals [10]. Low solubility of Zn is the major cause for the extensive occurrence of Zn deficiency in crops [11]. To overcome these challenges, agronomic fortification of Zn could be a possible solution. Pooniya et al. [12] reported that soil and foliar spray of Zn is an effective solution to avoid Zn deficiency in rice. Foliar application of Zn improves the Zn concentration in grains by about 30%, 25% and 63% in rice, wheat and maize grains, respectively, over soil application [13,14]. Agronomic biofortification of wheat by Zn fertilization is a promising way to resolve Zn deficiency problems [15]. Likewise, iron is also an essential micronutrient for plant growth and metabolism, especially in chlorophyll synthesis and for the maintenance of chloroplast structure and function. Iron deficiency in many crop plants results in reduced yields with reduction in nutritional quality [16]. Iron can bind directly to the protein, or as haem, an important constituent of blood hemoglobin [17]. Any practice of nutrient management, which either decreases or increases the supply of another nutrient element or its absorption from the soil by plants or translocation and mobility within the plant, will influence its nutrition and, thereby, the nutrient use efficiency and crop yield [18]. The efficiency of applied P rarely exceeds 30%, while that of most of the micronutrient cations is more than 10%. Particularly, Zn use efficiency is very low (2%). Therefore, their repeated applications over the years lead to their build up and interactions in soils and plants, affecting agricultural production [19]. The heavy use of P fertilisers may have some adverse or favorable effect on the availability of applied Zn in soils as well as its effect on plants [20]. Hence, the interaction effect between Zn and P is still very much contradictory. Ali et al. [21] reported that combined application of P–humate and Zn–humate were more effective in improving grain and straw yield than individually. Keeping the above facts in view, we hypothesised that an organic source of P has no or less antagonistic effect on Zn concentration and uptake by wheat crop. To test this hypothesis, phospho-enriched compost (PEC) was integrated with chemical fertiliser at different method and levels of Zn application. The objectives of the study were (i) to assess the effect of integrated P management and Zn application on wheat yield, concentration and uptake of P, Zn and Fe in wheat grain and straw and (ii) to analyse the effect of P and Zn on protein and amino acid concentration in the wheat grain under neutral to alkaline soil.

2. Material and Methods

The experimental site was situated in ICAR-Indian Agricultural Research Institute, New Delhi, India (28°40’ N and 77°12’ E). It has a semiarid, sub-tropical climate; the mean maximum temperature during July is about 40 °C, while the mean minimum temperature in the January is as low as 6 °C.
The annual average temperature is 25.6 °C. The normal onset period of monsoon is in the third week of June. The mean annual rainfall is 614 mm, received during July–January. Soil belongs to order Inceptisol, Mahauli series. Texture of the soil is loamy in nature, leveled, percolating and fine drained, hypothermic family of the Typic Ustochrept (old alluvium). The initial chemical properties of the soil are shown in Table 1.

### Table 1. Initial soil parameter (0–15 cm) of the experimental field.

| Parameters       | Values                  |
|------------------|-------------------------|
| pH               | 7.3                     |
| Organic carbon   | 0.51%                   |
| Available nitrogen | 168.3 kg ha⁻¹         |
| Available phosphorus | 11.9 kg ha⁻¹          |
| Available potassium | 241.5 kg ha⁻¹       |
| Available Zn     | 0.68 mg kg⁻¹            |

The wheat straw was air dried and shredded to 8–10 cm pieces. Chopped straw was mixed with cow dung, soil and farmyard manure (FYM) in a ratio of 8:1:0.5:0.5. The rock phosphate (32% P₂O₅) was mixed with substrate mixture. To activate the microbial action, 1% urea was added to the substrate mixture. Treated straw mixture was put in 1 m³ concrete pits. The moisture was maintained initially at 100% (w/w) and later at 65%. After 30 days of decomposition when the thermophilic temperature subsided, the bio-inoculant *Aspergillus awamori* was applied at 300 g mycelia t⁻¹ of substrate. The fortnightly turnings were given to ensure thorough mixing and decomposition. The compost samples were drawn after four months of substrate decomposition. The samples were air-dried and homogenized by grinding. The compost so prepared was used for soil application.

The two-year field experiment on wheat was conducted during winter season (November–April) of 2012–13 and 2013–14. The treatments of the experiment included five phosphorus (P) management practices, including control (without P), 100% recommended dose of phosphorus (RDP) through chemical fertilizers (P₁₀₀-F), 100% RDP through phosphor-enriched compost (P₁₀₀-PEC), 50% RDP through PEC + 50% RDP through fertilizer (P₅₀-PEC + P₁₀₀-F) and 75% RDP through PEC + vesicular arbuscular mycorrhiza (VAM) + phosphate solubilizing bacteria (PSB) (P₇₅-PEC + VAM + PSB) and four levels of zinc, including control (without Zn), soil application of 25 kg ZnSO₄·7H₂O ha⁻¹ (25 kg soil), two foliar spray of 0.5% ZnSO₄·7H₂O at anthesis and one week after anthesis in wheat (two foliar spray), soil application of 12.5 kg ZnSO₄·7H₂O ha⁻¹ + one foliar spray of 0.5% ZnSO₄·7H₂O at one week after anthesis in wheat (soil + foliar spray). Thus, there were 20 treatment combinations of phosphorus and zinc applications. The treatments were set in a split plot design with three replications in fixed plots of size 4.2 m × 5 m each. A dose of 60 kg N and 40 kg K₂O ha⁻¹ was applied as basal dose during sowing. Subsequently, 60 kg N was applied in two equal splits as top dressing at first and second irrigation. Phosphorus was applied to the respective plots as per treatment through diammonium phosphate (DAP). Zinc was applied basally at the time of sowing as per treatment through zinc sulphate (ZnSO₄·7H₂O) that contained 21% zinc and 10% S. The amount of sulphur was adjusted through elemental sulphur in all the plots and applied one week before sowing of crop. The inoculum species used for PSB and VAM were *Pseudomonas striata* and *Glomus fasciculatum*, respectively.

For estimation of P, plant samples were digested with di-acid mixture (HNO₃:HClO₄ in 9:4). The P content in the extracts was determined by stannous chloride method [22]. This extract was subsequently used for Zn and Fe estimation. Zinc and iron (Fe) in plant extracts were determined by atomic absorption spectrophotometer from the extract prepared for the estimation of phosphorus as outlined above and expressed in mg kg⁻¹. The P, Zn and Fe uptakes in grain or straw were worked out by multiplying their respective nutrient concentrations with the corresponding yield. The total uptakes of nutrients were determined by adding up their respective uptake in grain and straw. Protein content in wheat grain was calculated by multiplying N content by the factor 5.85 [23]. The amino acid
composition, such as tryptophan content, lysine and methionine contents were determined by using the protocols developed by Horn et al. [24]; Spies and Chambers [25]; and Felker et al. [26].

Data collected from different treatments with three replications were subjected to the analysis of variance in split-plot design. Statistical analysis of the data was performed using SPSS software (version 11.0). Test of significance of the treatment differences was done on the basis of ‘T’ test. The significant differences between treatments were compared with the Duncan’s multiple range test at 5% level of significance. Correlation and regression were performed to know the effect of yield attributes, and P concentration on wheat grain yield.

3. Results and Discussion

3.1. Yield and Yield Parameters

The application of P$_{50}$-PEC + P$_{50}$-F resulted in significantly higher yield attributes, such as spikes m$^{-2}$, grains spike$^{-1}$, test weight, spike length and spikelets spike$^{-1}$ than P$_{100}$-F. However, it was at par with P$_{100}$-PEC and the minimum values of yield parameters were observed in plots without P (Table 2, Figure 1). The increase in grain yield with application of P$_{50}$-PEC + P$_{50}$-F over P$_{100}$-F was 11.3%. This increase was due to improvement in yield components and improved bioavailability of residual soil phosphorus [27]. The differences in grain and straw yields among the different treatments were also associated with differences in grain and shoot P concentrations (Table 3), revealing that P enrichment in grain and straw is more important to improve crop productivity. The application of PEC along with chemical fertiliser provided continuous and ready availability of both macro and micro-nutrients, which, in turn, enhanced the yield of wheat crop. Matar and Brown [28] reported that early and continuous P uptake increases yield potential of crops in both the cropping seasons by stimulating growth and development of plants.

Soil application + foliar spray of Zn resulted in significantly larger yield attributes, such as spikes m$^{-2}$, test weight, spike length and spikelets spike$^{-1}$, and was at par with 25 kg-Soil application of Zn (Table 2 and Figure 1). However, the grains spike$^{-1}$ were significantly superior with 25 kg-Soil application of Zn and at par with soil + foliar spray of Zn. Significantly lower values of all yield attributes were observed from plots without Zn. The grain and straw yields of wheat were highest with 25 kg-Soil application of Zn; the second highest yields were produced by the crop receiving soil + foliar spray of Zn. The 25 kg-Soil application of Zn resulted in 16.7% yield enhancement over plots without Zn. The increase in yield parameters and yield could be attributed to the proper supply of Zn up to the harvesting stage in soil + foliar applied plots and enhancement of various enzymatic activities leading to increased photosynthetic activity and dry matter accumulation, which in turn led to higher yield attributes and yield [29–32]. Alloway [33] described that Zn improves photosynthesis, transformation of carbohydrates and seed development. Thus, increased Zn content and uptake resulted in bolder grains, finally improving test weight. These results are supported by the findings of Nawaz et al. [34], who reported that Zn application improved the wheat yield over control. Imran and Rehim [35] also revealed that soil + foliar application would be more beneficial for improving plant growth and yield over soil application alone.
Table 2. Influence of integrated P management and Zn application on yield, yield attributes and protein percent in wheat grain (average of 2 years).

| Treatments                  | Spikes m⁻² | Grains Spike⁻¹ | Test Weight (g) | Spike Length (cm) | Spikelets Spike⁻¹ | Grain Yield (t ha⁻¹) | Straw Yield (t ha⁻¹) | Protein (%) |
|-----------------------------|------------|----------------|-----------------|-------------------|-------------------|-----------------------|--------------------|-------------|
|                             |            |                |                 |                   |                   |                       |                    |             |
| Without P                   | 302 d      | 36.1 d         | 35.9 c          | 9.4 d             | 26.8 d            | 3.65 d                | 5.90 d             | 9.5 d |
| P₁₀₀-F                     | 327 c      | 36.8 c         | 36.1 c          | 10.3 c            | 29.7 c            | 4.03 c                | 6.19 c             | 10.0 c |
| P₁₀₀-PEC                    | 353 a      | 44.3 b         | 40.4 a          | 11.7 a            | 33.7 a            | 4.77 a                | 7.09 a             | 11.3 ab |
| P₃₀-PEC + P₅₀-F            | 358 a      | 46.4 a         | 40.6 a          | 11.8 a            | 34.7 a            | 4.81 a                | 7.20 a             | 11.5 a |
| P₇₅-PEC + VAM + PSB        | 341 b      | 42.5 b         | 39.2 b          | 11.1 b            | 32.0 b            | 4.58 b                | 6.68 b             | 11.2 b |
|                             |            |                |                 |                   |                   |                       |                    |             |
| Without Zn                  | 316 c      | 36.1 b         | 36.6 b          | 10.1 b            | 29.1 b            | 4.08 c                | 6.16 c             | 10.1 b |
| 25 kg-Soil                  | 352 a      | 44.7 a         | 40.2 a          | 11.5 a            | 33.4 a            | 4.61 a                | 7.01 a             | 11.3 a |
| Two foliar **               | 325 b      | 36.3 b         | 36.3 b          | 10.1 b            | 29.5 b            | 4.19 b                | 6.36 b             | 10.2 b |
| Soil + Foliar *             | 352 a      | 44.1 a         | 40.7 a          | 11.6 a            | 33.6 a            | 4.59 a                | 6.92 a             | 11.2 a |

**—Two foliar spray at anthesis and one week after anthesis stage; *—one foliar spray at one week after anthesis stage. Similar letter in a column indicates non-significance difference between treatments.

Figure 1. Relationship between grain yield and yield parameters. (a) Grains spike⁻¹, (b) spikelets spike⁻¹ and (c) spikes m⁻².

3.2. Phosphorus Concentration and Uptake

The P concentration in grain as well as in straw was highest with P₁₀₀-PEC followed by P₅₀-PEC + P₅₀-F and P₇₅-PEC + VAM + PSB (Table 3). The P uptake in grain was found highest with P₁₀₀-PEC and the uptake of P in straw and total P uptake were highest with P₅₀-PEC + P₅₀-F. The percent increase in wheat grain P concentration due to P₁₀₀-PEC over without P was 39.2%. This might be due to better availability and consistent supply of P from PEC and chemical fertiliser up to harvest and also increased microbial activity in soil helping to increase the P uptake and leading to increased concentration in grain and straw [36,37]. The near perfect linear relationship of grain yield with grain P concentration showed that differences in yield were associated with differences in grain P concentration and their
corresponding uptake (Figure 2). These results firmly revealed that P uptake is of greater significance in enhancing crop productivity. Zaki and Radwan [38] reported that application of P fertilizer and PSB enhanced P and micronutrients availability and concentration in plants. Shivay et al. [39] reported that minute quantity of fertilizer P is bioavailable for plant uptake. The bioavailable P in the soil was found to be higher whenever an organic source of P was applied externally. The increased P levels proportionately increased the bioavailable P in the soil, which caused the increased P concentration and uptake in wheat parts.

The P concentration in grain and straw was highest with two foliar sprays of Zn followed by soil + foliar spray of Zn. However, the highest P uptake was noticed with soil + foliar spray of Zn. The increase in grain P concentration with two foliar sprays of Zn over 25 kg-Soil application of Zn was 9%. This trend could likely be due the antagonistic effect of excessive Zn on P-absorption and further translocation from roots to other parts of the plants. However, the Zn application by foliar spray increased P-absorption from the soil by plants [11]. Soil Zn application increased the N and P concentration but at higher dose reduced the P concentration [40].

The P concentration in grain and straw was highest with two foliar sprays of Zn followed by soil + foliar spray of Zn. However, the highest P uptake was noticed with soil + foliar spray of Zn. The increase in grain P concentration with two foliar sprays of Zn over 25 kg-Soil application of Zn was 9%. This trend could likely be due the antagonistic effect of excessive Zn on P-absorption and further translocation from roots to other parts of the plants. However, the Zn application by foliar spray increased P-absorption from the soil by plants [11]. Soil Zn application increased the N and P concentration but at higher dose reduced the P concentration [40].

**Table 3. Influence of integrated P management and Zn application on P concentration and uptake by wheat (average of 2 years).**

| Treatments | Grain P Concentration (%) | Straw P Concentration (%) | Grain P (kg ha⁻¹) | Straw P (kg ha⁻¹) | Total P (kg ha⁻¹) |
|------------|--------------------------|--------------------------|-------------------|------------------|------------------|
| **Phosphorus levels** | | | | | |
| Without P | 0.28 c | 0.13 b | 10.4 c | 7.6 c | 17.9 d |
| P100-F | 0.3 b | 0.13 b | 13.5 b | 8.2 c | 21.7 c |
| P100-PEC | 0.38 a | 0.15 a | 18.1 a | 10.5 b | 28.6 a |
| P50-PEC + P50-F | 0.37 a | 0.15 a | 18.0 a | 11.0 a | 29.0 a |
| P75-PEC + VAM + PSB | 0.38 a | 0.15 a | 17.3 a | 10.2 b | 27.4 b |
| **Application of ZnSO₄·7H₂O** | | | | | |
| Without Zn | 0.34 b | 0.15 a | 13.9 c | 9.1 b | 23.0 d |
| 25 kg-Soil | 0.33 b | 0.13 c | 15.6 b | 9.1 b | 24.7 c |
| Two foliar ** | 0.36 a | 0.15 a | 15.4 b | 9.8 a | 25.2 b |
| Soil + Foliar * | 0.36 a | 0.14 b | 16.9 a | 10.0 a | 26.9 a |

**—Two foliar spray at anthesis and one week after anthesis stage; *—one foliar spray at one week after anthesis stage. Similar letter in a column indicates non-significance difference between treatments.**

**Figure 2. Response of grain P uptake to grain yield of wheat (grain P uptake with grain yield of wheat under different P and Zn levels were taken for this response calculation).**
3.3. Zinc Concentration and Uptake

There were significant differences among treatments for Zn concentration and uptake in wheat (Table 4). The Zn concentration and uptake in wheat were significantly higher with P<sub>50</sub>-PEC+ P<sub>50</sub>-F followed by P<sub>100</sub>-PEC; the lowest Zn concentration in grain and straw was noticed with P<sub>100</sub>-F. The increase in grain Zn concentration with P<sub>50</sub>-PEC+ P<sub>50</sub>-F over P<sub>100</sub>-F was 13.3%. The increased Zn concentration with integrated P management resulted from the reduction in antagonistic effect of P on Zn when organic P was applied [41]. The decreased Zn concentration in grain and straw seen in P<sub>100</sub>-F plots might be due to dilution effect [42,43]. Ryan et al. [5] described that higher application of P fertilizers induces Zn deficiency in plants due to dilution effect. The Zn concentration in grain and straw was highest with two foliar sprays of Zn and it was at par with soil + foliar spray of Zn. The Zn uptake in grain, straw and total uptake of Zn were highest with soil + foliar spray of Zn. The increase in grain Zn concentration with two foliar sprays of Zn over 25 kg-Soil application of Zn was 10.4%. The results revealed that soil and foliar application of Zn are efficient in improving the Zn concentration in grains as nutrients are absorbed quickly through leaves as compared to uptake from the plant roots [35,44]. Similar results were obtained by Ghasal et al. [45]; they reported that soil + foliar application of Zn increased Zn uptake by 4–7% over soil application alone. Habib [46] found that the concentration of Zn in wheat increased by three times by foliar application of Zn at the reproductive stage of the crop. Ghasal et al. [47] reported that Zn concentration in grain increases significantly with an increase in Zn level in soil.

| Treatments | Grain Zn Concentration (%) | Strain Zn Concentration (%) | Grain Zn (mg kg<sup>-1</sup>) | Strain Zn (mg kg<sup>-1</sup>) | Total Zn (mg kg<sup>-1</sup>) |
|------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Without P  | 34.9<sup>b</sup> | 56.5<sup>a</sup> | 127.7<sup>c</sup> | 335<sup>c</sup> | 463<sup>d</sup> |
| P<sub>100</sub>-F | 31.5<sup>c</sup> | 50.6<sup>c</sup> | 127.0<sup>c</sup> | 313<sup>d</sup> | 440<sup>d</sup> |
| P<sub>100</sub>-PEC | 35.6<sup>a</sup> | 57.2<sup>a</sup> | 170.5<sup>a</sup> | 407<sup>a</sup> | 578<sup>a</sup> |
| P<sub>50</sub>-PEC+ P<sub>50</sub>-F | 35.6<sup>a</sup> | 57.3<sup>a</sup> | 171.9<sup>a</sup> | 414<sup>a</sup> | 586<sup>a</sup> |
| P<sub>75</sub>-PEC+ VAM + PSB | 34.6<sup>b</sup> | 55.5<sup>b</sup> | 158.9<sup>b</sup> | 371<sup>b</sup> | 530<sup>b</sup> |

**—Two foliar sprays at anthesis and one week after anthesis stage; *—one foliar spray at one week after anthesis stage. Similar letter in a column indicates non-significance difference between treatments.

3.4. Iron Concentration and Uptake

There was a significant increase in Fe concentration and uptake due to the application of P<sub>50</sub>-PEC+ P<sub>50</sub>-F followed by P<sub>100</sub>-PEC over without P and P<sub>100</sub>-F (Table 5). The increase in wheat grain Fe concentration over P<sub>100</sub>-F was 13.4%. The lowest Fe concentration and uptake were noticed in plots without P. As the P also exhibited a negative effect on absorption and translocation of Fe, the application of P<sub>100</sub>-F recorded lower Fe concentration over all other treatments. The application of PEC might have improved the chelation of Fe compounds and helped in absorption of Fe from soil. Two foliar sprays of Zn and soil + foliar spray of Zn improved Fe concentration and uptakes in grain and straw of wheat significantly compared to without Zn treatment. However, soil + foliar spray of Zn resulted in the highest grain, straw and total uptake of Fe because of higher dry matter production. This study indicated that soil application of Zn reduced the Fe absorption from soil. These results are in agreement
with the findings of Abbas et al. [48]. Haldar and Mandal [49] reported that Fe may get accumulated in the roots, and higher root Zn might reduce the Fe translocation from root to shoot or may reduce the uptake from soil itself.

**Table 5.** Influence of integrated P management and Zn application on Fe concentration and uptake by wheat (pooled data of two years).

| Treatments                  | Grain Fe Concentration (%) | Straw Fe Concentration (%) | Grain Fe (mg⁻¹ kg) | Straw Fe (mg⁻¹ kg) | Total Fe (g kg⁻¹) |
|-----------------------------|---------------------------|---------------------------|-------------------|-------------------|------------------|
| Without P                  | 27.5 c                    | 389 abc                    | 100 c             | 2296 c            | 2.40 c           |
| P₁₀₀-F                     | 26.2 d                    | 380 d                      | 106 c             | 2355 c            | 2.46 c           |
| P₁₀₀-PEC                   | 29.3 b                    | 385 c                      | 140 a             | 2733 a            | 2.87 a           |
| P₅₀-PEC + P₅₀-F            | 29.7 a                    | 392 a                      | 143 a             | 2819 a            | 2.96 a           |
| P₇₅-PEC + VAM + PSB        | 28.6 b                    | 386 b                      | 131 b             | 2580 b            | 2.71 b           |

**Phosphorus levels**

**Application of ZnSO₄·7H₂O**

| Treatments                  | Grain Fe Concentration (%) | Straw Fe Concentration (%) | Grain Fe (mg⁻¹ kg) | Straw Fe (mg⁻¹ kg) | Total Fe (g kg⁻¹) |
|-----------------------------|---------------------------|---------------------------|-------------------|-------------------|------------------|
| Without Zn                  | 26.1 c                    | 386 c                     | 106 d             | 2374 d            | 2.5 c            |
| 25 kg-Soil                  | 26.6 c                    | 371 d                     | 124 c             | 2603 b            | 2.7 b            |
| Two foliar **               | 30.9 a                    | 398 a                     | 130 b             | 2533 c            | 2.7 b            |
| Soil + Foliar *             | 29.4 b                    | 392 b                     | 136 a             | 2717 a            | 2.9 a            |

**—Two foliar sprays at anthesis and one week after anthesis stage; *—one foliar spray at one week after anthesis stage. Similar letter in a column indicates non-significance difference between treatments.**

### 3.5. Protein and Amino Acids Content

The treatment P₅₀-PEC + P₅₀-F resulted in significantly higher crude protein, lysine, methionine and tryptophan contents compared to all other treatments (Table 1 and Figure 2). The increase in crude protein percentage in grain with the application of P₅₀-PEC + P₅₀-F was 15% over control. This might be due to the increased phosphorus concentration in soil by addition of organic matter and release of native P by more microbial activity. P has been found to enhance higher root growth, N uptake and metabolism, thereby the protein concentration in grain increased considerably. P has been necessary for both nitrate reductase activity and nitrate uptake and may influence the enzyme directly or indirectly, thereby leading to higher protein synthesis. P deficiency led to reduction in nitrate reductase activity, thereby reducing protein synthesis. So, optimum N and P supplementation through organic or inorganic sources of nutrient is a prerequisite to improve protein synthesis. Zinc application also exerted significant influence on crude protein and amino acid contents in grain. Incorporating 25 kg of Zn into soil resulted in significant improvement in crude protein, lysine, methionine and tryptophan contents in grain over control treatment; the respective increase was 11.8% (Figure 3). However, this treatment did not differ significantly from soil + foliar spray of Zn for any of these grain quality parameters. The results indicated that Zn plays an important role in increasing protein and amino acid content in grains. Zn is a stimulant factor which increases the production of indoleacetic acid; thereby it leads to an increase in amino acid and protein content. Zn has a role in improving β-carotene content of wheat and thereby improving protein and other quality parameters in wheat [50]. Soil and foliar application of Zn improved dry matter accumulation and higher N uptake which in turn resulted in higher crude protein content in grains [51]. Zinc deficiency is related to N metabolism; whenever the Zn levels in plants are lowered, the proteins concentration decreases considerably. Zn deficiency leads to impairment of both synthesis and structural integrity of RNA and ribosomes, further lead to higher RNase activity. So, adequate Zn supplementation is required for protein synthesis [52]. Gao et al. [53] reported a positive correlation between Zn content in wheat grain and grain protein content. Ozturk et al. [54] revealed that highest Zn uptake and protein synthesis occurs at same stage of seed formation.
A correlation matrix (Table 6) showed significant correlations ($P < 0.05$) of all the different yield attributes and nutrient uptake parameters, with grain yields of wheat. This indicated that yield parameter, nutrient concentration and their uptake have significant contribution towards yield enhancement in wheat.

Table 6. Correlation matrix between grain yield, yield attributes and nutrients uptake of wheat.

|        | GY | S   | GS   | TW  | SL   | SS   | Grain P | Grain Zn | Grain Fe |
|--------|----|-----|------|-----|-----|------|---------|----------|----------|
| GY     | 1.000 |     |      |     |     |      |         |          |          |
| S      | 0.971 ** | 1.000 |      |     |     |      |         |          |          |
| GS     | 0.980 ** | 0.988 ** | 1.000 |     |     |      |         |          |          |
| TW     | 0.931 ** | 0.938 ** | 0.960 ** | 1.000 |      |      |         |          |          |
| SL     | 0.973 ** | 0.990 ** | 0.993 ** | 0.968 ** | 1.000 |     |         |          |          |
| SS     | 0.978 ** | 0.994 ** | 0.995 ** | 0.956 ** | 0.996 ** | 1.000 |         |          |          |
| Grain P| 0.963 ** | 0.904 ** | 0.902 ** | 0.828 ** | 0.897 ** | 0.906 ** | 1.000 |          |          |
| Grain Zn| 0.869 ** | 0.869 ** | 0.841 ** | 0.858 ** | 0.846 ** | 0.856 ** | 0.854 ** | 1.000 |          |
| Grain Fe| 0.911 ** | 0.869 ** | 0.849 ** | 0.823 ** | 0.848 ** | 0.867 ** | 0.941 ** | 0.962 ** | 1.000 |

GY: grain yield; S: spikes m$^{-2}$; GS: grains spike$^{-1}$; TW: test weight; SL: spike length; SS: Spikelets spike$^{-1}$. ** Indicate significance at 1% level.

4. Conclusions

The results obtained from the experiment provide us major findings on the influence of integrated P management and Zn on yield and quality parameters of wheat. Application of 50% of recommended P through chemical fertilizer and 50% of recommended P through PEC with soil + foliar application of Zn increased yield, nutrient concentration and uptake over control treatments. Increased yield, nutrient concentration and quality of wheat might have been caused by reduced antagonistic effect of P on Zn and Fe with the application of phospho-enriched compost (PEC) and increased bioavailability of Zn to plants. The results of this study indicate that application of 50% of recommended P through chemical fertilizer and 50% of recommended P through PEC with soil application of 12.5 kg ha$^{-1}$ of ZnSO$_4$ as basal dose + one foliar spray of ZnSO$_4$ at 0.5% during one week after anthesis stage is more promising for higher productivity and quality of wheat.

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