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Effect of K and Zn Application on Biometric and Physiological Parameters of Different Maize Genotypes

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Abstract: Potassium (K) and zinc (Zn) are mineral nutrients required for adequate plant growth, enzyme activation, water retention and photosynthetic activities. However, Pakistani soils are alkaline and have serious problems regarding Zn deficiency. The current study aims at finding the nutrient–nutrient interaction of K and Zn to affect maize plants' (i) physiological processes and (ii) productivity. For this purpose, a pot experiment was conducted at the research area of the Department of Soil Science, Faculty of Agricultural Science and Technology, Bahauddin Zakariya University, Multan. Two maize genotypes, DK-6142 (hybrid) and Neelam (non-hybrid), were used with three K fertilizer doses, i.e., 0, 60 and 100 kg ha^{−1} in all possible combinations with three Zn fertilizer doses, i.e., 0, 16 and 24 kg ha^{−1}. The treatments were replicated under a completely randomized block design. The results elucidated that the combined application of K and Zn with K60 + Zn16 treatment significantly increased agronomic, productive, and physiological attributes. It has improved fresh biomass (89%), dry biomass (94%), membrane stability index (142%), relative water content (200%) and chlorophyll contents (191%) as compared to the control. Moreover, the mineral uptake of K and Zn was significantly improved with their maximum fertilization rate in hybrid genotype compared to non-hybrid and CK.

Keywords: potassium; zinc; maize; physiological attributes

1. Introduction

Maize (*Zea mays* L.) is a C₄ plant belonging to the family Poaceae. In Pakistan, it is considered the third most important cereal crop, after wheat and rice. Moreover, various human communities consume it as staple food and animal feed in different parts of the world, including Africa, America and Asia [1,2]. It is also certified as a rich source of protein content (up to 15%). In 2019–2020, the total maize cultivation area was 1404.2 thousand hectares, while maize production was 7.88 million tonnes in Pakistan, contributing about 0.6% in Gross Domestic Production (GDP) [3]. Because of its accumulative significance, progress in the agronomic physiognomies of maize has received great reverence in Pakistan [4].

Potassium (K) is one of the primary macronutrients required by plants to complete their life span. Its fertilization stimulates root growth significantly, enhancing water uptake

from soil to the plant body [5,6]. In the same way, it decreases the transpiration rate and helps in water conservation during drought conditions [7]. In addition, it has a significant contribution in activating many enzymes, maintains the turgor pressure, the electric potential gradient and the balance between cations and anions [8,9]. According to [10], K content present in plant tissues is capable of the appropriate functioning of numerous processes directly involved in crop growth, development, and yield. Consequently, the regular application of a balanced dose of K is necessary to maintain soil fertility, optimum crop growth and yield for a longer run.

Zinc (Zn) plays a crucial role in the metabolic activities of major proteins among plants and humans and is hence considered as an essential nutrient for all organisms [5,11]. According to [12], Zn is indirectly involved in carbohydrate metabolism, it is a structural constituent of many enzymes involved in different processes such as photosynthesis, the metabolism of different proteins, pollen germination and maintaining membrane integrity also provide resistance against various pathogens. Pakistani soils have low organic matter contents (0.4–0.7%) and are abundant in calcium carbonate (CaCO_3), mainly maintaining a high pH (7.5–8.4). Moreover, the cation exchange capacity (CEC) is formally controlled by Calcium (Ca) and such factors are key reasons to limit the plant-available Zn and to reduce the crop yield in absence of Zn fertilizer [5]. However, Zn application in these soils helps to improve the nutritional status of crop and enhance grain production [13]. Maize is a source of macro- and micronutrients in the human diet, which helps in a balanced diet. The deficiency of Zn in maize could induce Zn deficiency in humans using maize as staple food [14,15]. According to Krebs [16], the problems produced due to Zn deficiency are very common in children. According to the previous studies, maize genotype plays a vital role in grain Zn uptake [17–19]. The concentration of Zn present in maize grain is about 20 mg kg^{-1} on an average basis [20,21], so its bioavailability in humans/animals is insufficient.

Limited knowledge is available in the literature about the interaction of these two mineral nutrients (K and Zn) and their effectiveness on maize growth and yield. So, it is promising that the soil with a marginal deficiency of these nutrients have no capacity to ensure optimum yield of maize without balanced fertilization of K and Zn. This gives rise to the need for the current study to investigate the efficiency of different Zn and K rates applied to maize genotypes (hybrid and non-hybrid) for efficient mineral uptake. The major aims of current study were to (i) identify the nutrient–nutrient interaction between K and Zn in the agroecosystem, (ii) elucidate the effectiveness of the combined application of K and Zn on maize physiology and (iii) define the impacts of K and Zn fertilization on yield in different genotypes.

2. Material and Methods

2.1. Site Description

To investigate the above-mentioned aims, a pot experiment was conducted at the research area of the Department of Soil Science (30.258° N , 71.515° E), Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan. Multan city is located in the arid and subtropical region of Pakistan [22]. The maximum recorded temperature is approximately 54° C , and the lowest recorded temperature is approximately 4.5° C . The average rainfall is roughly 186 mm. Dust storms are of frequent occurrence within the city. The soil used in the experiment was alkaline calcareous and deficient in plant-available Zn (0.54 mg kg^{-1}) and K (75.0 mg kg^{-1}). The physicochemical properties of soil used for pot experiment are as given in Table 1.

2.2. Experiment Details

The study was conducted in a wire-house under ambient conditions. The moisture contents were visually checked every day, and the pots were irrigated frequently (3–4 times a week) to maintain the water contents at field capacity level. The soil used in the experiment was sieved through 2 mm mesh. Soil samples were used to measure the soil

textural class [23,24], organic matter [25] and extractable K [26]. Electrical conductivity (inoLab® Cond 7110, Xylem Analytics, Weilheim, Germany) and pH (METTLER TOLEDO, Jenway, UK) of soil samples were measured through soil extract and saturated soil paste, respectively. Soil sample was taken in a conical flask with AB-DTPA extraction solution and shaken for 15 min at 180 cycles/minute, then filtrated. Atomic absorption spectrophotometry was used to determine the AB-DTPA extractable Zn in 1:2 soil solution (Thermo Scientific 3000 Series, Waltham, MA, USA; [27,28]). A three-factorial, completely randomized design was followed where maize genotypes, i.e., hybrid Monsanto 'DK-6142' and non-hybrid 'Neelam', were used in all possible combination with three levels of K (0, 60 and 100 kg ha⁻¹) and three levels of Zn (0, 16 and 24 kg ha⁻¹). Approximately, 20 kg soil was added to each pot having 38 cm height, 27 cm diameter, 0.0572 m² surface area and 0.02175 m³ volume. The pots were maintained at an adequate distance from each other, they were at (25 cm × 75 cm) row × plant distance to support easy movement during cultivation of plants. The experiment was conducted for one growth season, and the treatments were replicated three times.

Table 1. Physicochemical properties of soil used in the experiment.

Character	Unit	Value
Texture		Loam
Sand	%	47.6
Silt	%	34.2
Clay	%	18.2
PHs	—	8.43
EC	dS m ⁻¹	0.72
CaCO ₃	%	4.67
Bulk density	Mg m ⁻³	1.30
Organic matter	%	0.57
AB-DTPA Extractable Zn	mg kg ⁻¹	0.54
Extractable K	mg kg ⁻¹	75.0

Five seeds of each genotype were sown in each pot. After one week of germination, thinning was conducted up to three plants per pot. Recommended dose of N (1.3 g per pot) and P₂O₅ fertilizer (1 g per pot) were used in the form of urea (contains 46% N; manufactured by Fauji Fertilizer Company Limited (FFC), Rawalpind, Pakistan) and diammonium phosphate (DAP contains 46% P, 18% N, manufactured by FFC, Pakistan), respectively. Urea was applied in two equal splits (i.e., at the time of sowing and 25 days after germination), while full recommended dose of DAP was added just before sowing. Potassium chloride (KCl) fertilizer also termed as Muriate of potash (MOP; 60% K₂O; manufactured by FFC, Pakistan) and zinc sulfate monohydrate (ZnSO₄·H₂O; 27% Zn; manufactured by FFC, Pakistan) were used as sources of K and Zn, respectively. As per treatment plan, K- and Zn-containing fertilizers were applied in soil as substrate just before sowing. All the fertilizers were thoroughly mixed with 20 kg soil.

2.3. Plant Harvest

Shoots and cobs were harvested at crop maturity (120 days after germination). After air-drying, each plant sample was placed in an oven at 65 °C for 48 h until constant weight was achieved. After oven drying, samples were ground and digested using a diacid mixture with HClO₄:HNO₃ in 1:2 ratio (72% and 69% pure) [29]. For digestion, ground plant samples and HNO₃ were added to the flasks and stood overnight. Afterward, heated at 125° for 1 h using hot plate. Then, the samples were cooled down to avoid drying out, and HClO₄ was added until colorless solution was obtained. Digested plant samples were used for further analysis. All the chemicals used in the experiment were bought from Eastern Scientific Corporation Private limited and were of analytical grade manufactured by Merck.

2.4. Plant Analysis

2.4.1. Morphological and Yield Parameters

Morphological and yield parameters, including plant height (cm), fresh weight (g), dry weight (g), cob length (cm) and 1000 grain weight (g) were measured after harvesting.

2.4.2. Physiological Parameters

The plant physiological parameters of all the treatments were recorded in the morning (between 09:30 to 10:30 am). Fully expanded second leaf of each plant was selected for the measurements of gaseous exchange parameters and chlorophyll content at principal growth stage 5: Inflorescence emergence (BBCH-51). Gaseous exchange parameters such as photosynthetic rate (A), transpiration rate (E), stomatal conductance (Gs) and internal CO₂ concentration (Ci) were recorded using infrared gas analyzer (IRGA: type 225 mk3; Analytical Development Company, Hoddesdon, UK). Chlorophyll contents (SPAD value) were measured using SPAD-meter (SPAD-502, Minolta, Osaka, Japan). Relative water contents (RWC) were estimated using the following formula [5]:

$$\text{RWC} = (\text{Fresh weight} - \text{Dry weight}) / (\text{Turgid weight} - \text{Dry weight}) \times 100$$

Membrane stability index (MSI) was calculated by the formula [30] as given below:

$$\text{MSI} = \{I - (C1/C2)\} \times 100$$

2.4.3. Ionic Parameters

At maturity, the straw and cobs samples were collected, and oven dried until constant weight was achieved. Afterward, the grains were removed and both straw and grain samples were ground. Following wet digestion method, the straw and grain samples were placed in diacid mixture (HNO₃: HClO₄, 2:1 ratio) separately in conical flasks overnight, then digested separately on hot plate (at 150 °C for 1 h, afterward at 235 °C for 30 min). The concentration of K was determined by flame photometer (FP 6410, Shanghai Jingke, China) [23], and Zn was determined using atomic absorption spectrophotometer (Thermo Scientific 3000 Series, Waltham, MA, USA).

2.5. Statistical Analysis

A completely randomized design (CRD) with three-factorial arrangement was analyzed. Statistix 9[®] (Analytical Software, Tallahassee, FL, USA) was used for analysis of variance (ANOVA) and Microsoft Excel 2013[®] (Microsoft Corporation, Redmond, WA, USA) were used for data computations. Least significant difference (LSD) test based on Duncan multiple comparisons was used to identify the significant differences among the treatment means [31]. The treatments were tested in three replicates and the data presented with standard deviation in the graphs.

3. Results

3.1. Effect of K and Zn Fertilization on Plant Height

All the treatments showed a significant difference ($p \leq 0.05$) in the plant heights of both genotypes (hybrid and non-hybrid) with K and/or Zn application as compared to the control (Figure 1). Plant height increased significantly in the hybrid cultivar (DK-6142) with the application of K60, Zn16 (56.84%) followed by K100, Zn16 (53.42%) and K100, Zn24 (50.71%) in comparison with CK (K0, Zn0).

3.2. Effect of Potassium and Zinc Application on Plant Fresh and Dry Biomass (g Pot⁻¹)

Biomass production is considered as an important factor for fodder production for maize. The application of mineral nutrients such as K and Zn increased biomass production. A significant increase ($p \leq 0.05$) was observed in the fresh and dry biomass of both maize genotypes (hybrid and non-hybrid) through the combined application of Zn and K (ZnSO₄

+ MOP) in comparison with CK (Figure 2). Plant fresh biomass was significantly higher in the hybrid cultivar with the application of K60, Zn16 (89.73%) followed by K100, Zn16 (81.46%) and the inbred cultivar with the application of K60, Zn16 (74.03%) as compared to CK. Moreover, the plant dry biomass was increased with the application of K60, Zn16 (94.94%) followed by K100, Zn16 (85.08%) and K100, Zn24 (75.42%) in DK-6142 maize hybrid with respect to CK.

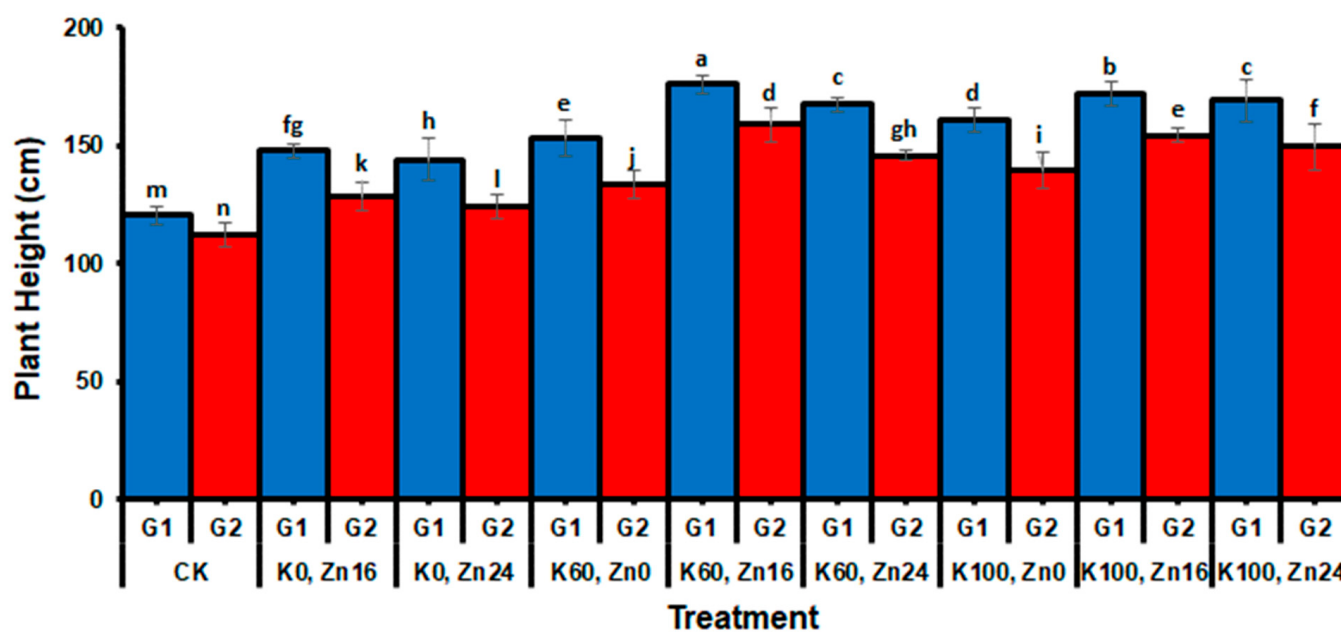


Figure 1. Effect of various levels of K and Zn on plant height of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha⁻¹, respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha⁻¹, respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

3.3. Effect of Potassium and Zinc on Membrane Stability Index (MSI) and Relative Water Content (RWC)

The application of mineral nutrients such as K and Zn increased the physiological parameters, i.e., the MSI and RWC, in the maize plants. A significant increase ($p \leq 0.05$) was observed in the MSI (%) and RWC (%) of both maize genotypes through the combined application of Zn and K (ZnSO₄ + MOP) compared to maize under control conditions where no Zn and K was applied (Figure 3). The maximum MSI was observed in the hybrid variety with the application of K60, Zn16 (2.42 fold) followed by K100, Zn16 (2.35 fold) and K100, Zn24 (2.23 fold) as compared to CK. Meanwhile, the RWC was significantly enhanced in the DK-6142 hybrid with the application of K60, Zn16 (3.0 fold) followed by K100, Zn16 (2.73 fold) and the inbred 'Neelam' genotype with the application of K60, Zn16 (2.70 fold) as compared to CK.

3.4. Effect of Potassium and Zinc on Chlorophyll Contents (SPAD Value) and Cob Length (cm)

Comparatively, DK-6142 performed better than Neelam under various fertilization treatments. The chlorophyll content (SPAD value) was significantly increased ($p \leq 0.05$) in the DK-6142 maize hybrid with the application of K60, Zn16 (2.91 fold) followed by K100, Zn16 (2.67 fold) and the Neelam inbred genotype with the application of K60, Zn16 (2.65 fold) as compared to CK (Figure 4). Moreover, cob length was increased with the application of K60, Zn16 in maize hybrid (68.47%) and inbred cultivar (60.71%) followed by maize hybrid with the application of K100, Zn16 (60.16%).

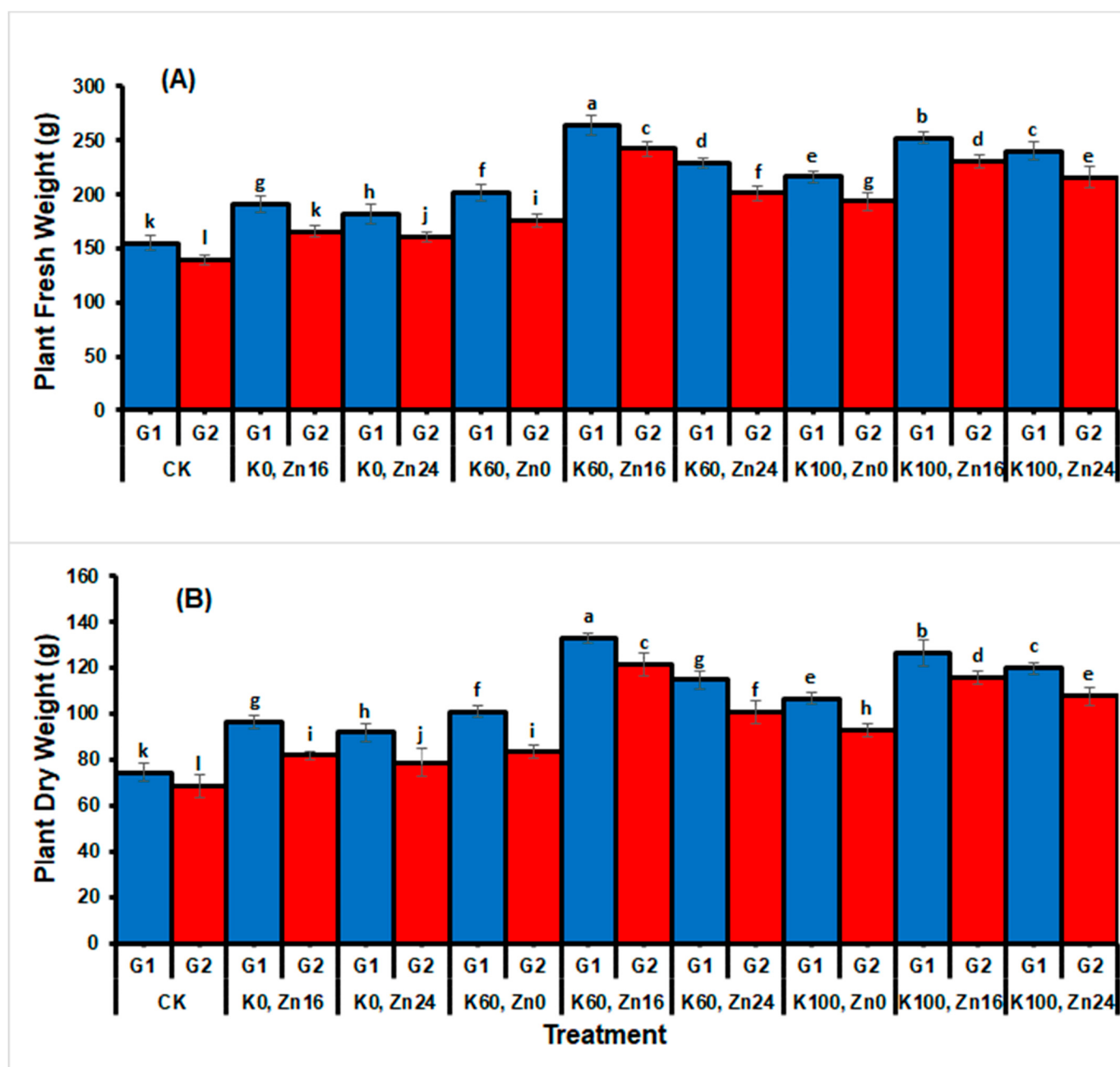


Figure 2. Effect of MOP and ZnSO_4 on (A) fresh weight and (B) dry weight of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha^{-1} , respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha^{-1} , respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

3.5. Effect of Potassium and Zinc on Gas Exchange Parameters

Gas exchange parameters such as photosynthetic rate (A), transpiration rate (E), stomatal conductance (G_s), and internal CO_2 concentration (C_i) are important and the main components of plant growth and development. A significant increase ($p \leq 0.05$) was observed in gas exchange parameters i.e., A and E (Figures 5 and 6). Photosynthetic rate significantly improved with the application of K60, Zn16 in maize hybrid (3.54 fold) and inbred genotype (3.15 fold) followed by hybrid DK-6142 with the application of K100, Zn16 (3.05 fold), respectively.

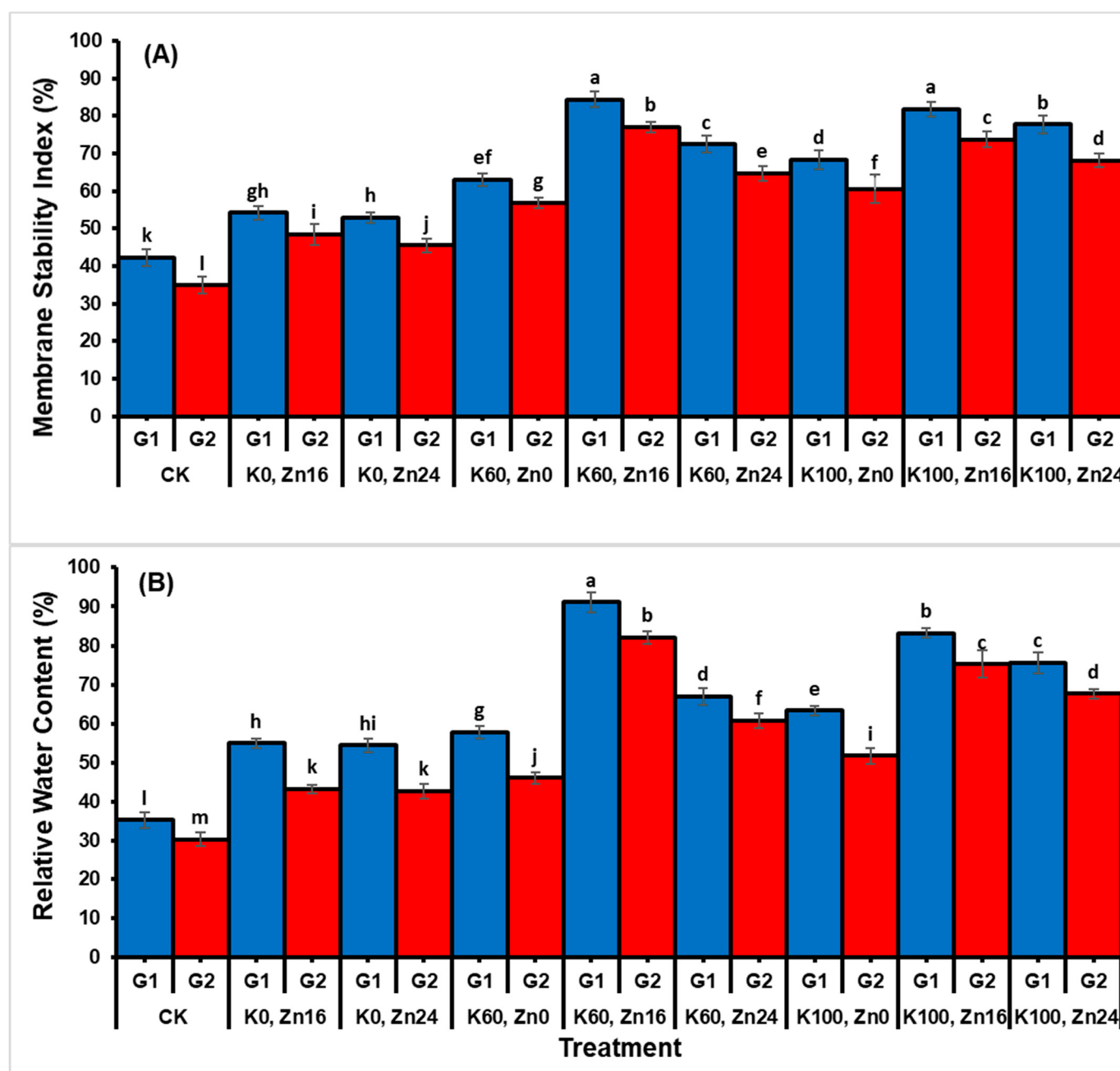


Figure 3. Effect of MOP and ZnSO_4 on (A) Membrane stability index and (B) Relative water content of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha^{-1} , respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha^{-1} , respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

Transpiration rate also enhanced with the application of K60, Zn16 in DK-6142 maize hybrid (4.38 fold) and Neelam genotype (4.08 fold) followed by DK-6142 hybrid with K100, Zn16 (3.94 fold) in comparison with CK. Moreover, stomatal conductance increased in DK-6142 with the application of K60, Zn16 and in Neelam with K60, Zn16 followed by K100, Zn16 in hybrid cultivar showed similar results (3.58 fold) in relation to CK.

Internal CO_2 concentration were also increased with the application of K60, Zn16 in hybrid (2.20 fold) and inbred (2.05 fold) cultivars followed by DK-6142 with the application of K100, Zn16 (103.01%) in comparison with CK.

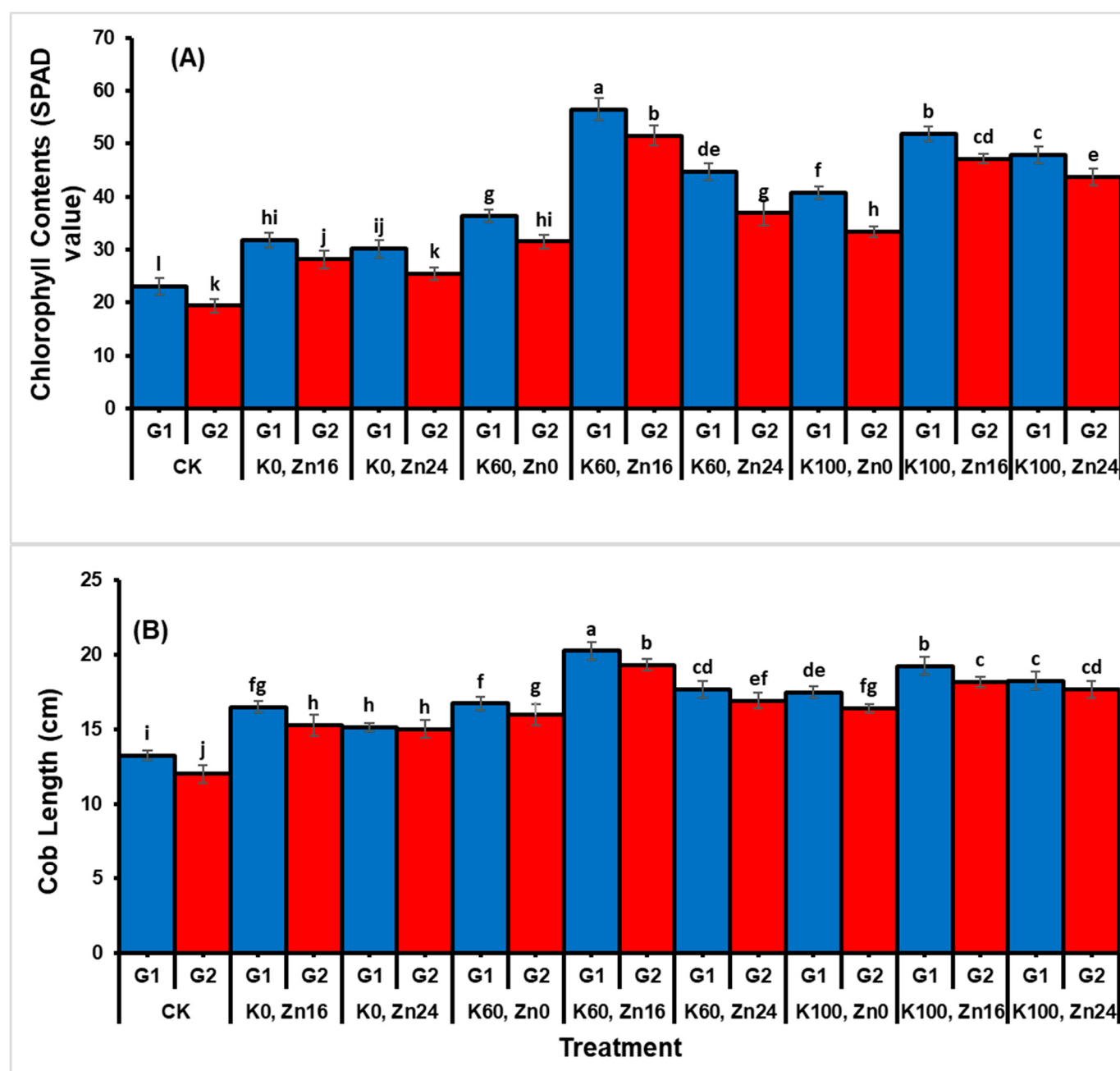


Figure 4. Effect of MOP and ZnSO_4 on (A) chlorophyll contents and (B) cob length of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha⁻¹, respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha⁻¹, respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

3.6. Effect of Potassium and Zinc on 1000 Grain Weight and Grain Yield of a Maize

A significant increase ($p \leq 0.05$) was observed in the 1000 grain weight (g) and grain yield (g pot⁻¹) of maize in all treatments compared to the control (Figure 7). The results showed that the 1000 grain weight was increased with the application of K60, Zn16 in the DK-6142 maize hybrid (30.99%) and in the inbred Neelam (26.33%) genotypes, followed by DK-6142 at K100, Zn16 (25.68%). So, it was clear from the data that the hybrid genotype performed better than the non-hybrid genotype. Moreover, the grain yield was also improved with the application of K60, Zn16 in the hybrid (39.74%) and inbred genotypes (35.27%) followed by K100, Zn16 (32.70%) in hybrid cultivar as compared to CK.

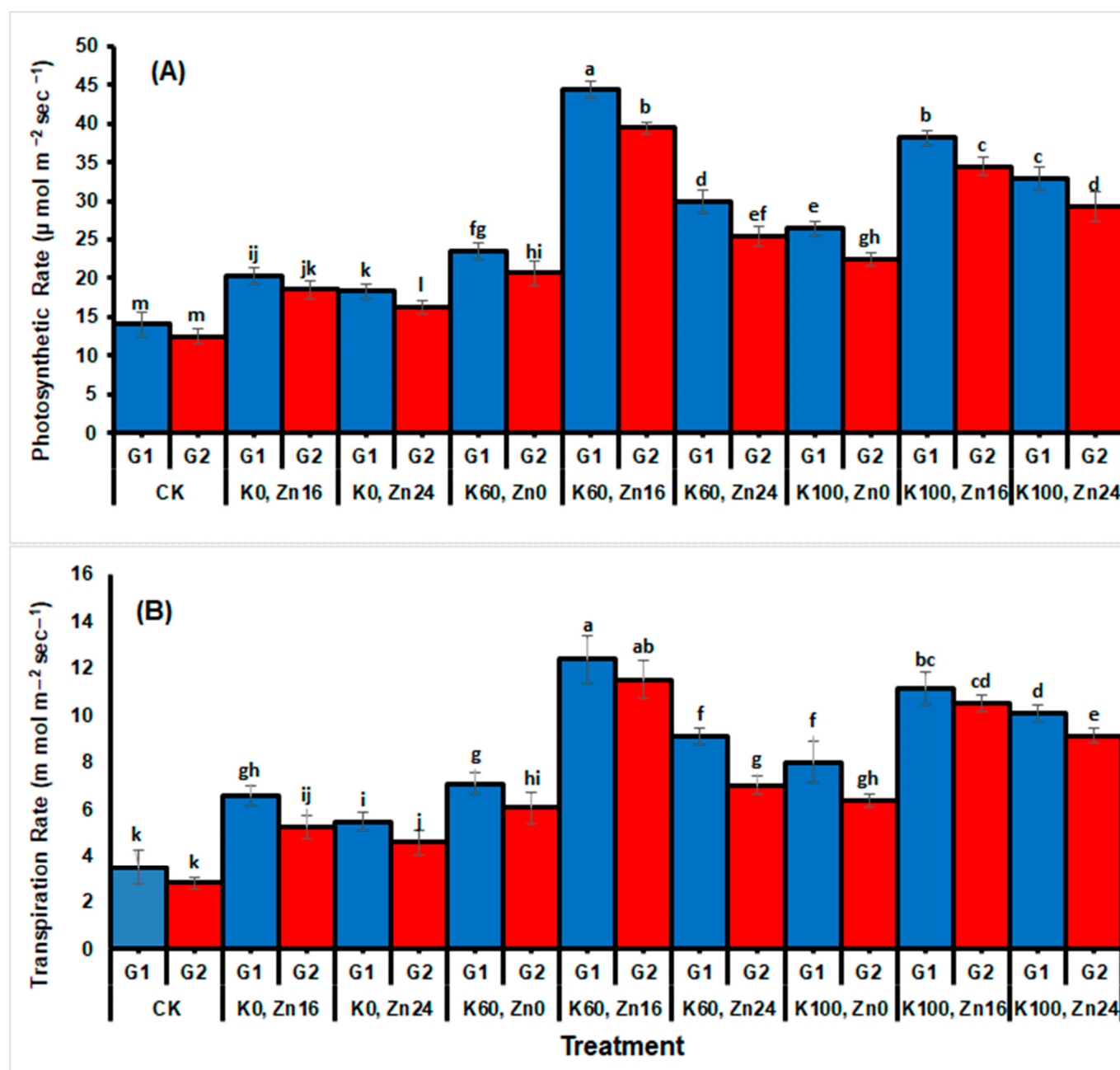


Figure 5. Effect of MOP and ZnSO_4 on (A) photosynthetic rate and (B) transpiration rate of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha^{-1} , respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha^{-1} , respectively. The presented data are the means $\pm$ SD ($n = 3$). The lower case letters indicate statistically significant differences according to the LSD test.

3.7. Effect of Potassium and Zinc on K Concentration in Straw and Grain of a Maize

A significant increase ($p \leq 0.05$) was observed in the K concentration in the straw and grain of the maize through the combined application of K and Zn compared to under control conditions (Figure 8). The straw K concentration improved in the hybrid cultivar with the application of K100, Zn24 (94.06%), followed by K100, Zn0 (93.28%) and K100, Zn16 (92.25%). It clarifies that the hybrid cultivar performed better than the inbred plants.

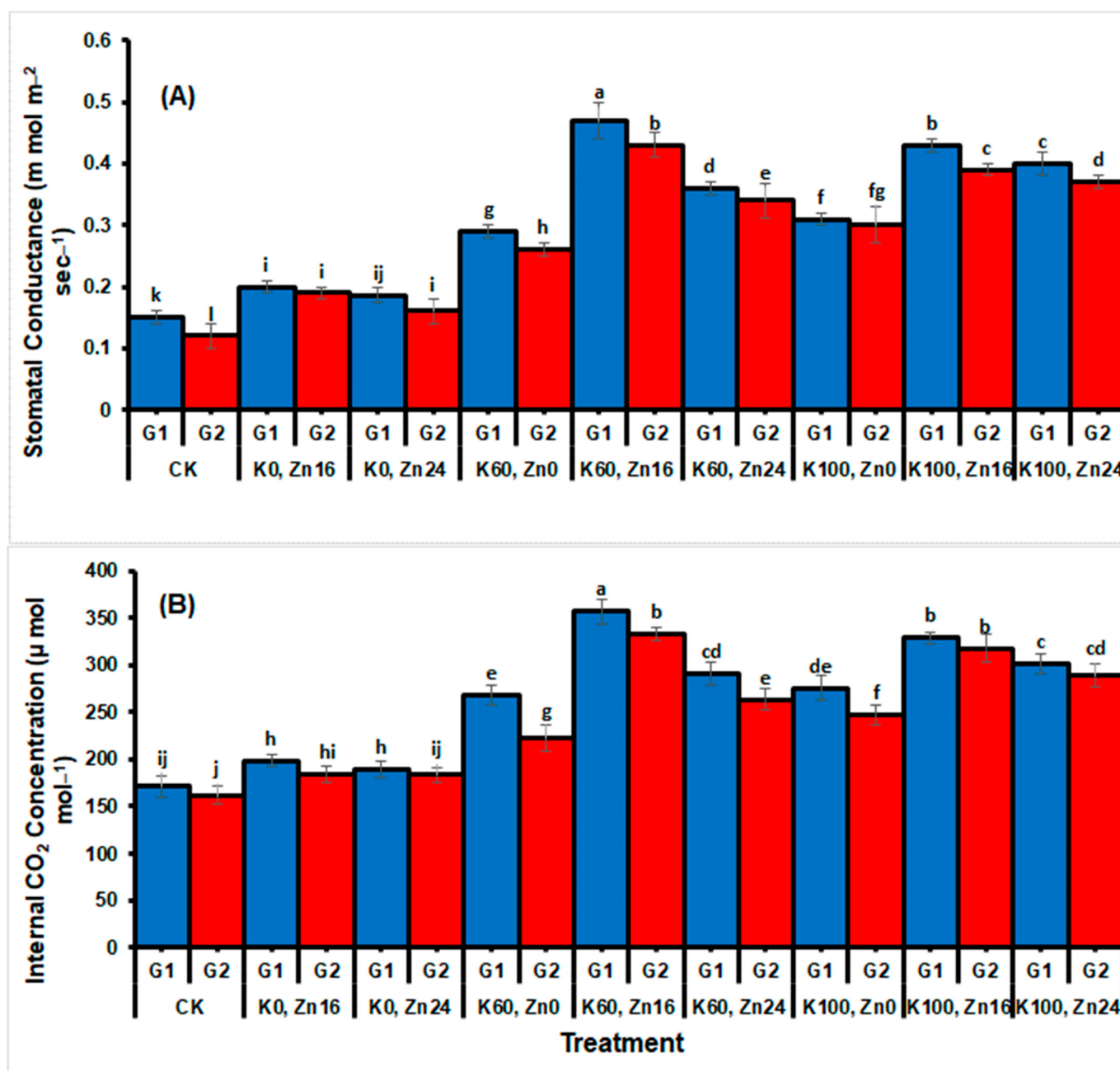


Figure 6. Effect of MOP and ZnSO_4 on (A) stomatal conductance and (B) internal CO_2 concentration of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha^{-1} , respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha^{-1} , respectively. The presented data are the means $\pm$ SD ($n = 3$). The lower case letters indicate statistically significant differences according to the LSD test.

On the other hand, a significant increase ($p \leq 0.05$) was observed in the case of K concentration in maize grain, through the various combined application of ZnSO_4 and MOP than the control (Figure 8). The grain K concentration increased in the hybrid variety with the application of K100, Zn24 (43.48%), followed by K100, Zn16 (42.39%) and K100, Zn0 (40.58%).

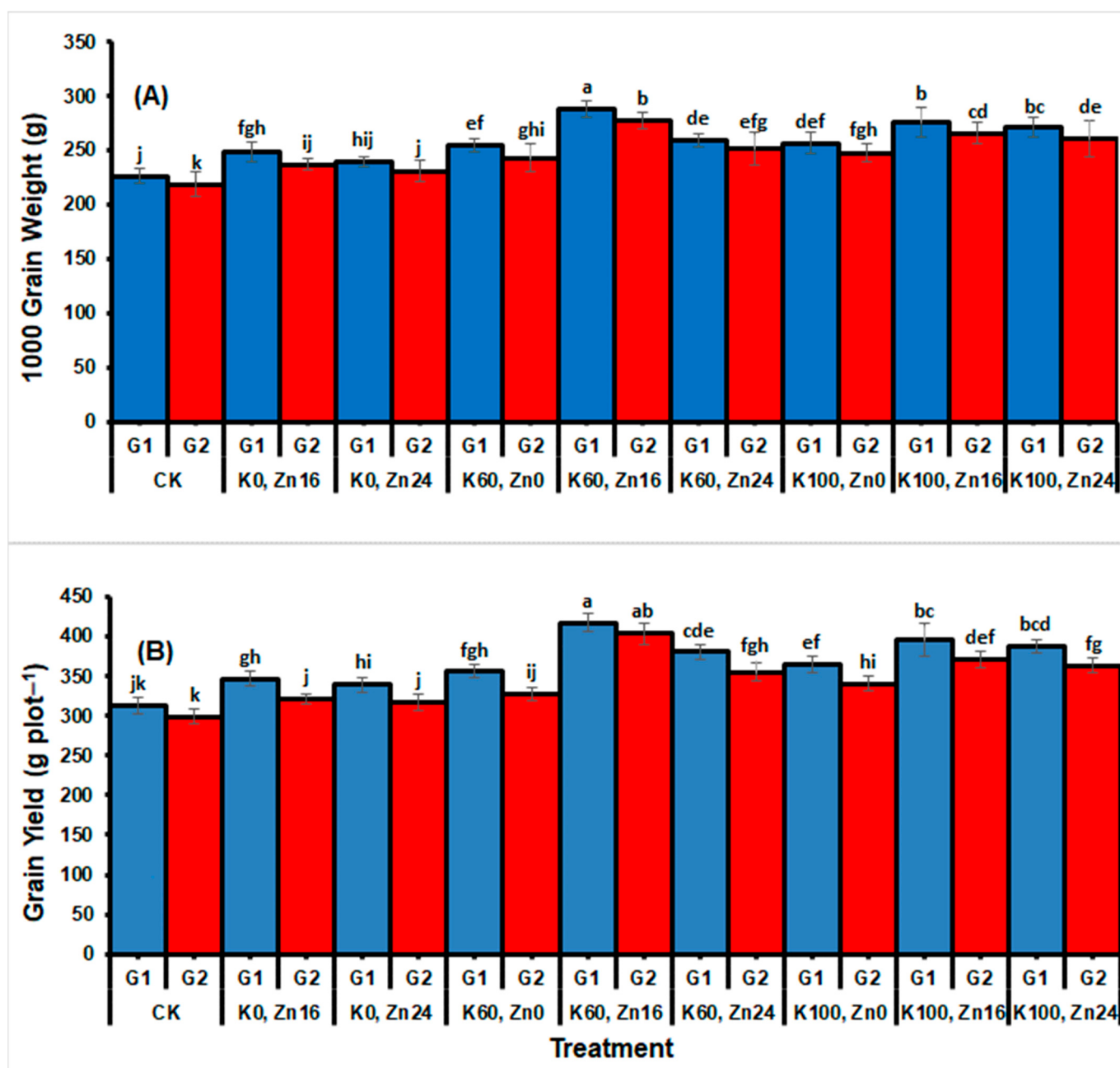


Figure 7. Effect of MOP and ZnSO₄ on (A) 1000 grain weight and (B) grain yield (g pot⁻¹) of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha⁻¹, respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha⁻¹, respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

3.8. Effect of Potassium and Zinc on Zn Concentration in Straw and Grain of a Maize

Due to various combined applications of ZnSO₄ + MOP, a significant increase ($p \leq 0.05$) was observed in the Zn concentration in the straw (mg kg⁻¹) and grain (mg kg⁻¹) of maize compared to the control (Figure 9). The zinc concentration in straw improved in G1 significantly with the application of K0, Zn24 (3.40 fold), followed by K100, Zn24 (3.35 fold) and K60, Zn24 (3.21 fold). In the case of the Zn concentration in grain (mg kg⁻¹), G1 showed better results with the application of K0, Zn24 (2.63 fold), followed by K100, Zn24 (2.58 fold) and K60, Zn24 (2.46 fold) compared with CK.

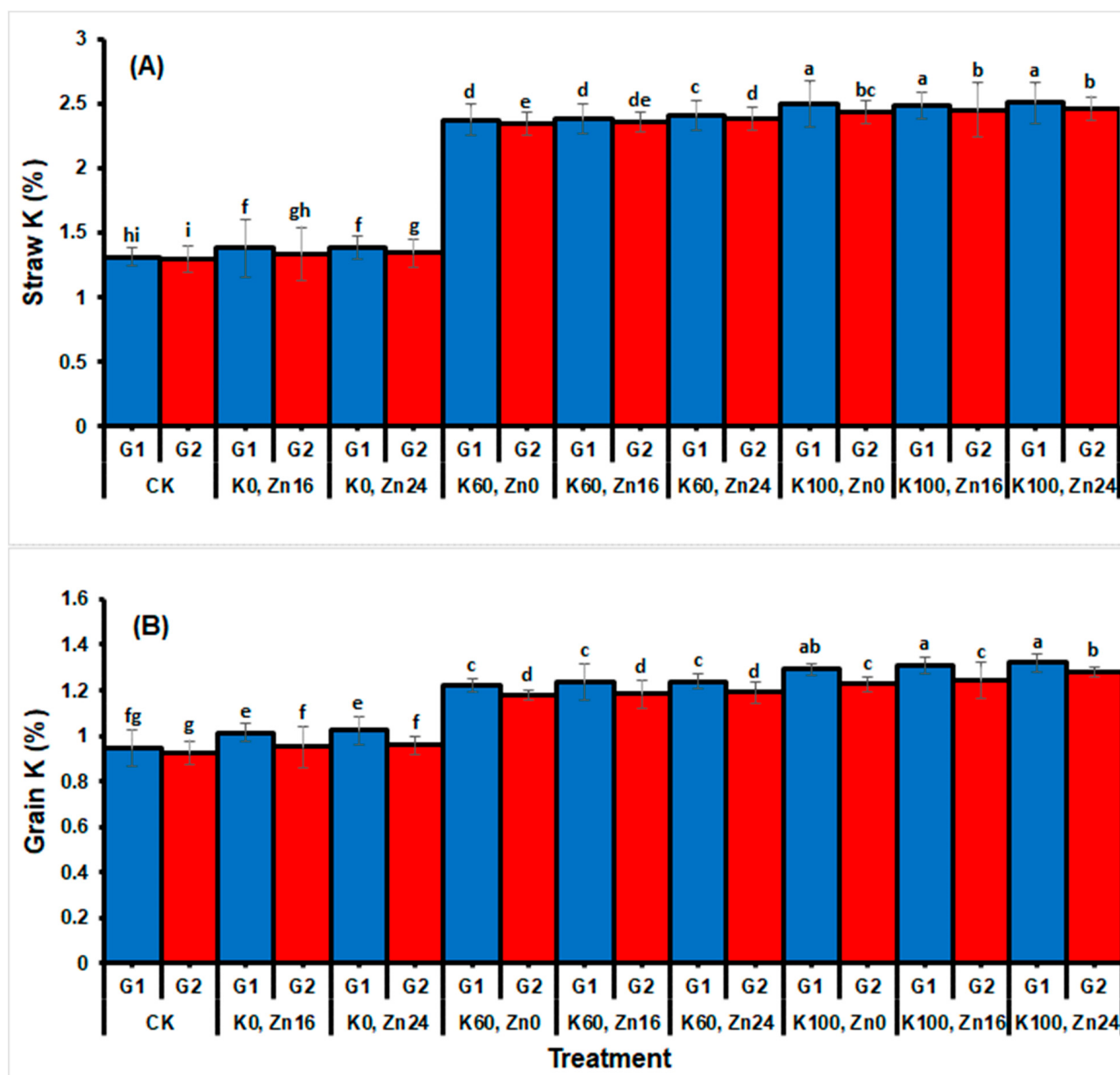


Figure 8. Effect of MOP and ZnSO_4 on (A) straw K and (B) grain K of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha⁻¹, respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha⁻¹, respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

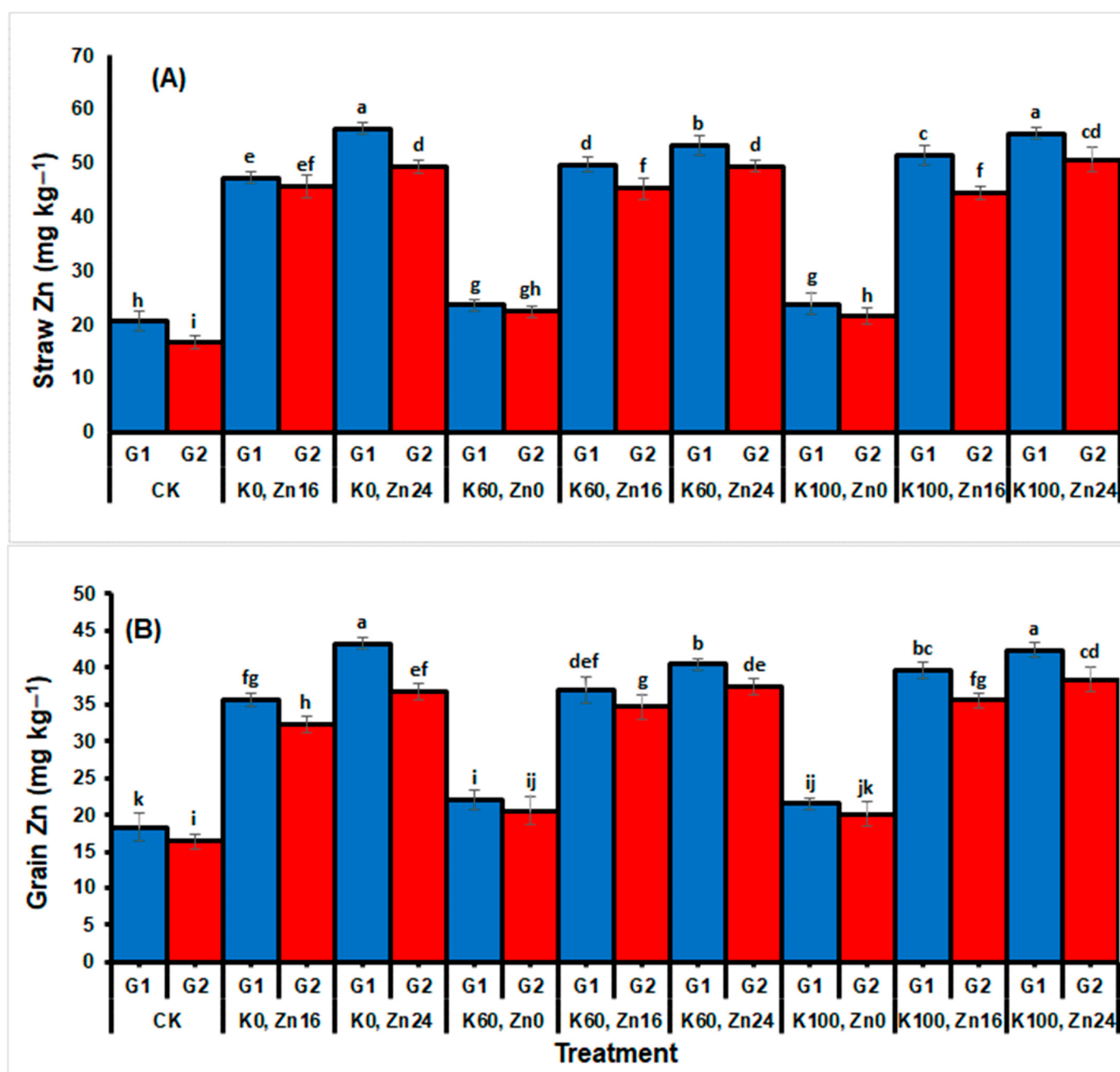


Figure 9. Effect of MOP and ZnSO₄ on (A) straw Zn and (B) grain Zn of hybrid (G1) and non-hybrid (G2) genotypes of a maize plant; K0, K60 and K100 represent 0, 60 and 100 kg K ha⁻¹, respectively; Z0, Z16 and Z24 represent 0, 16 and 24 kg Zn ha⁻¹, respectively. The presented data are the means $\pm$ SD ($n = 3$). The lowercase letters indicate statistically significant differences according to the LSD test.

4. Discussion

4.1. Effect of Potassium and Zinc Application on Growth Attributes of Maize Genotypes

Zinc deficiency is common in Pakistani soils, which are alkaline calcareous in natural conditions. Other important reasons for the K and Zn deficiency is the frequent use of tubewell water and less availability of canal water [32]. So, under such conditions, a combined fertilization approach plays an important role in improving crop growth and yield. In the present study, the combined application of MOP and ZnSO₄ caused a significant increase in the plant height along with the fresh and dry biomass of maize because the combined application of K and Zn improves the root growth which helps in increasing

the uptake of K and also increasing the crop growth by improving the photosynthetic rate [33]. This increase is due to the involvement of Zn in many enzymatic reactions, the synthesis of chlorophyll, stomatal regulation, protein synthesis and carbohydrates transformation [5,34]. On the other hand, K also plays an important role in enhancing crop growth [7,35,36]. Potassium is also involved in increasing plants' dry biomass [6] because it increases the photosynthetic activity, which results in increasing the number of carbohydrates. According to Marschner [9], K increases the dry biomass of a plant under stress condition by enhancing the carboxylation efficiency.

4.2. Effect of Potassium and Zinc Application on Gas Exchange Parameters of Maize Genotypes

The application of K and Zn improved the gas exchange parameters (A, E, Ci and Gs) of both maize genotypes. Actually, both these nutrients have a key role in enzymatic activities such as CO₂ fixation. In the present study, the gas exchange parameters of maize hybrid DK-6142 increased by K and Zn application. Similar findings were also observed by [35,37], as they also reported the beneficial impact of K and Zn for the gas exchange parameters. According to [38], the photosynthetic rate is controlled by the application of K because it is directly involved in the opening and closing of stomata. Moreover, Zn maintains the water contents at tissue level at high rates [9]. Both the stomatal and non-stomatal factors are involved in controlling the direct relationship of photosynthesis with the seed yield and dry matter production of crop plants [37].

4.3. Effect of Potassium and Zinc Application on Physiological Attributes of Maize Genotypes

The physiological attributes such as the membrane stability index, the relative water content and the chlorophyll contents are the key factors for the estimation of plant growth parameters. The application of K and Zn improved all the mentioned physiological attributes of the maize genotypes. These results are also in agreement with findings of [39], who reported that the RWC and the osmotic potential were significantly improved through the application of Zn. These results can be related to the findings of some previous studies in which it was concluded that increase in leaf Zn due to supplemental Zn increased the leaf turgor and the RWC of soybean [40] and wheat [41].

The photosynthesis rate is limited in response to dehydration due to the closure of the stomata and defects in metabolic processes, and the total amount of chlorophyll is reduced [42]. Potassium and Zn application improve conditions to increase chlorophyll concentration and photosynthesis. The chlorophyll content in living plants is one of the important factors for preserving photosynthetic capacity [43]. The researchers concluded that possibly the deficiency in micro-nutrients could prevent the activity of a number of antioxidant enzymes, resulting in oxidative damage to chlorophyll [13,44]. Increasing the chlorophyll content is attributed to increasing the nutrients availability, especially Zn and K, and increasing the availability of other elements. Zinc application at different stages of plant growth may result in less nutrients loss and consequently increases nutrients' availability for the plants which in turn increase the chlorophyll content. Zinc application does not directly affect the formation of chlorophyll, but it can affect the concentration of elements that are part of the chlorophyll molecule, such as iron and magnesium [45]. Various studies have observed similar findings [5,46].

4.4. Effect of Potassium and Zinc Application on Yield Parameters of Maize Genotypes

The data clarified that the application of K and Zn significantly increased the cob length, 1000 grain weight and grain yield of maize plants. Potassium plays a vital role in crop growth and yield such as it is involved in water use efficiency (WUE), the division of cells, stomatal regulation, protein synthesis as well as hydrocarbon formation and their transfer towards cereal grains [9]. According to Broadley [11], various physiochemical processes directly or indirectly depend on Zn fertilization, which play an important role in enhancing dry matter production as well as the grain yield of cereals crops [35,47]. The combined application of K and Zn has a positive impact on the 1000 grain weight of a

maize plants because the enzymes involved in carbohydrate synthesis are Zn dependent, and Zn plays a role in stomatal regulation and in the transformation of photosynthetase from source to sink [9]. So, K improves the plant's growth and yield due to significant enhancements in yield attributes [48], and also from its different role in different plant metabolic procedures [49].

4.5. Effect of Potassium and Zinc Application on Ionic Contents of Maize Genotypes

The results revealed that the combined application of K100, Zn24 significantly increased straw K (94.06%) and grain K (43.48%), whereas K0, Zn24 increased Zn concentration in straw (240.58%) and grain (163.84%). There are different essential nutrients which are present in soil with different concentrations. Some of these nutrients interact with each other; these interactions may be antagonistic or synergistic in nature. According to Maleki [50], the root surface is directly related to the absorption of nutrients, which is due to the positive interaction of K and Zn that enhance the lateral as well as fibrous root system of plant. This beneficial interaction also increases the concentration of N, P and K in soil solution, which affects the root system that uptakes more nutrients and increases the crop growth and development [33]. The concentration of K increases with the increase in K application [5,6], which may be due to the increase in the concentration of K in the soil solution as well as in the exchange site that is evident from the greater K concentration in the crop plant [51].

According to Liu [5,52], the positive effect of Zn application on the K content and its uptake by wheat and rice can be determined by the Zn-induced increase in the root system, which is due to the formation and polar transportation of indole acetic acid (IAA) that could affect more absorption of K. According to the work of Harris [2], two important methods that could be used to increase the plant Zn concentration are seed priming as well as soil zinc fertilization. Other important things for better Zn uptake are the soil bioavailable Zn and the surface area of plant roots [47].

5. Conclusions

The current study revealed that a combined fertilization (Zn + K) approach significantly enhanced the agronomic, physiological, growth and yield parameters of two maize genotypes compared to those under control conditions. The combined fertilization of Zn + K increases the K concentration in the grain and straw of maize, while the Zn concentration increases in the grain and straw of maize genotypes under solely Zn application. It was also concluded that the hybrid maize genotype (DK-1642) performed better than the non-hybrid (Neelam) genotype.

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