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Research Article

Evaluation of Variable Rates of Zinc Sulfate Fertilization on Soil Chemical Characteristics, Fertility Status, and Growth Components of Wheat (*Triticum aestivum*): A Case Study on the Hilly Region of Uthal, Balochistan

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ABSTRACT

Fertilization of field crops with zinc (Zn) has recently been a significant consideration worldwide due to deficiency and malnutrition. This research study aimed to evaluate the impact of different levels of zinc sulfate, combined with nitrogen and phosphorous fertilizers on soil properties, morphological characteristics of plants, plant growth, yield attributes, and their interaction with soil properties. The research experiment was conducted in a randomized complete block design with Six variable rates of ZnSO-4 (0, 4.5, 9.5, 14.5, 19.5, and 24.5 kgha-1) arranged in a triplicate. The analysis results showed a 15-20% significant effect of increased rate of Zn fertilization on plant growth (plant height, leaf length, spike length, and fertile tiller formation), biological and grain yield of wheat compared to control. The mean maximum of biological (18018.33±820.63 and 17219.66±1261.41 kgha-1) and grain yield (4233.33±121.027 and 4000±58.13 kgha-1) were observed in T5 and T4 (ZnSO-4 rate 24.5 and 19.5 kgha-1) compared to control (8675.66±228.92 and 2863.33±46.99 kgha-1). Additionally; the results of the co-relation matrix showed a positive significant ($p<0.05$) effect among the various soil and plant parameters, while; the negative significant ($p<0.05$) was observed in soil pH, and non-significant ($p<0.05$) was observed in soil EC (dsm-1). Conclusively; this study's findings suggested that ZnSO-4 at the rate of 24.5 kgha-1 could improve the interaction among the soil and plant nutrition that enhanced the morphological characteristic of wheat and ultimately influenced biological and grain yield kgha-1 of wheat in the hilly areas of Balochistan.

Keywords: Zinc, Nitrogen, Wheat, Fertile Tillers, Grain Yield, Nutrient Interaction.

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is cultivated worldwide and is also known as a vital crop of food security, the primary source of plant-based human nourishment. Pakistan is an agricultural country that shares 19.5% GDP and 14% value added in agriculture (Gatto et al., 2021; Usmani et al., 2020), and 42% of employment and labor directly or indirectly involved in this sector (Ahmed et al., 2024). In Pakistan annually out of total land 9.0 million ha are used for wheat cultivation with the production of 24.0 million tons, whereas; in Balochistan 388.416 thousand hectares with a production of 842.734 thousand tons, overall an average annual wheat yield of irrigated and rain-fed is 2.9 and 1.3 respectively (Haider et al., 2019). However, the growth parameters and yield of wheat depends on soil fertility and nutrient availability in the soil solutions.

Normally; the fertility level of Pakistani soils varies from region to region and depends on the ability and facilitation of the growers, and such things will lead to the additional application of both fertilizers (organic and In-organic) to optimize the yield of wheat crops and to increase fertility level of the soil (Ahmed et al., 2024). Fertility is the capability of the soil to provide essential nutrients in adequate amounts required by plants (Nguemezi et al., 2020). Furthermore; wheat requires a large amount of nutrients for their growth and optimum yield, along with the maco-nutrient Zn is also required by plants for their growth and their interaction with soil properties (Dhaliwal et al., 2022; Sehgal et al., 2017; Shehzadi et al., 2024). Zn is one of the essential micro-nutrients that plays a major role in enzyme activity, bio-synthesis, growth hormones, and synthesis of carbohydrates, proteins, chlorophyll content, and growth of the plant (Faizan et al., 2021). Though; plants require a small amount of Zn concentrations as play several roles in the plant such as seedling vigor, plant and seed grain membrane, sugar formation, improved drought, and heat stress. Zn deficiency is very common generally in Pakistani soil and particularly in Balochistan. However; Zn concentration is also inadequate in some areas of Pakistan, but the availability of Zn concentration is deficient due to the soil, environmental conditions, pH, EC, CEC, and SOM%, yet the application of available P fertilizers is also affected by the availability of Zn concentration in the soil solutions and increase salt tolerance in plant (Adeel et al., 2024; Singh et al., 2023).

Wheat losses of 18.3% frequently occurred in plain areas of Pakistan affected by drought and heat stress, leading to a loss of production of 2.5md/acre (Ahmed et al., 2024; Sehgal et al., 2017). Drought and heat stress directly decline the productivity of photosynthesis (Qadir et al., 2018). Additionally; calcareous soil is commonly deficient in available Zn, and as a result low productivity and income. Such challenges of low crop productivity and inadequate quantity of mineral content lead the innovative agricultural practices.

In many studies, it has been revealed that the addition of an additional amount of $ZnSO^{-4}$ could increase wheat grain yield, grain quality, and quality of protein (Corpas and Palma, 2020; Guerrini et al., 2020; Jalal et al., 2022; Wang et al., 2018). Moreover, Zn deficiency in wheat could be recorded initially on lower leaves and then move to words the younger leaves causing leaf chlorosis, poor plant growth, and necrosis on leaves (Azeem et al., 2023; Joy et al., 2017). Additionally; Zinc fertilization also affects the availability of major nutrients NPK due to strong coordination with each other's (Wilson et al., 2020; Zhu et al., 2015). Since the last decade with rapid cultivation and imbalance of nutrient management nowadays zinc deficiency has been recorded all over the world, particularly in arid and semi-arid regions with calcareous, tropical hilly weather soils with sandy textured different environments recorded to be a more serious effect on crop growth, and yield attributes (Thapa et al., 2022; Wahid et al., 2022).

MATERIALS AND METHODS

Lasbela combines the words Las "a plain" and Bela "a forest". District Lasbela is 24^0 53'02 to 26^0 39' 20" north longitude and 65^0 12' 11" to 67^0 25' 39" east longitude. The north border is shared with Khuzdar, the south border shares the Arabian Sea, the eastern border is shared with Karachi the Capital of Sindh province, and the western border is shared with the Gwadar and Awaran districts of Balochistan. The summer is long (from March to August) with a short winter (December to January), with a mean minimum to maximum temperature ranging between 25 to 52 ^{0}C and 178 mm of an average rainfall/annum (Ahmed et al., 2024).

Detail of research experiments:

The main purpose of this study was to estimate the impact of variable rates of zinc sulfate fertilization on soil physicochemical characteristics, the growth component of wheat *(Triticum aestivum),* and the interaction among the various soil properties, and the growth and yield component of wheat. Thus; for study purposes, a plot 4m X 5m in randomized complete block design (RCBD) arranged in a triplicate was conducted at the experimental farm of Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS) Uthal 2019-2020. While; the variable rates of Zinc sulfate ($ZnSO^-_4$) were T_0=control, T_1=4.5, T_2=9.5, T_3=14.5, T_4=19.5, and T_5=24.5kgha^{-1}. By-line sowing, manually Faisalabad wheat variety seed was sown on 15th November 2019-2020 at the rate of 100 kgha^{-1}. Nitrogen (N) and phosphorous (P) Fertilizers were applied at the rates 100 and 70kgha^{-1}, P was applied just before sowing the seed, and N and Zn were applied in three split doses 1st after germination of the seed, 2nd formation of tillers and 3rd booting. Additionally; the required plow application was carried out at the required time and before the cultivation of the field experiment.

Agronomic Observation:

Before harvesting of plant, randomly 5 healthy plants in triplicate from 18 plots were collected to evaluate the influence of different levels of $ZnSO^-_4$ on the plant growth and yield parameters such as plant height (cm), leaf length

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(cm), pedicle length (cm), spike length (cm), biological yield, seed grain yield, number of tillers formation, seed spike^{-1}, grain weight spike^{-1} and grain yield kgha^{-1}.

Soil sampling and processing:

Before and after the harvesting a total of 18 eighteen soil samples were collected at a depth of 0-15cm. The soil sample was labelled, packed, and transported to the Department of Soil Science, Faculty of Agriculture, LUAWMS to analyse soil physicochemical properties. Furthermore; samples were dried in the open air for 2-3 days, manually all stony and plant root material was collected and finally samples were sieved in 2mm in diameter. The soil and water extraction ratio was 1:2.5 for the analysis of soil EC (dSm^{-1}) through digital EC meter, pH through a digital pH meter, organic matter (%) by wet oxidation (Walkley and Black, 1934), total N (mgkg^{-1}), available P (mgkg^{-1}), extractable potassium K (mgkg^{-1}), and available zinc (mgkg^{-1}) followed by the international methods (Estefan, 2013; Jackson, 2005).

Plant sampling and processing:

The five healthy plant materials in triplicate from the experimental plots were collected, the material was washed with deionized water in an electric water bath, the washing material was left in the open air to minimize the excess water, and transferred to an oven at a temperature of 65^{0}C for 24 hours, and then material was placed in an electrical grinder to grind the plant material <1.0mm in size, and sieved through 1.0 mm sieve to organized a plant sample for the analysis of N and Zn concentration in plant followed by Estefan (2013).

Statistical analysis:

One-way analysis of variance (ANOVA) suggested by Gomes and Gomes, 1984. The differences among treatments mean will be calculated by the Least Significant Difference (LSD) test 5% probability level was used with the help of SPSS Version 20 (IBM.2016).

RESULTS

Soil characteristic of the experimental area

Before sowing of seed, the analysis results of soil basic properties are presented in Table 1 and showed non-significant (p<0.05) differences among the soil properties Mostly, the soil was sandy loam (sand 61.7, silt 26.3 and clay 12.0%), moderate in alkaline, low in SOM%, medium in available K, and low in N, P, and available Zn Table 1.

Table 1. Soil characteristics of the experimental area.

Treatments	EC (dSm^{-1})	pH	SOM (%)	N%	P mgkg^{-1}	K mgkg^{-1}	Zn mgkg^{-1}
T_0	0.46 ±0.102a	7.9 ±0.005a	0.251 ±0.020a	0.015 ±0.0016a	3.38 ±0.0101a	81.305 ±0.0359a	0.454 ±0.0222a
T_1	0.43 ±0.049a	7.9 ±0.036a	0.406 ±0.026a	0.037 ±0.0017a	3.39 ±0.0243a	81.542 ±0.0019a	0.675 ±0.0006a
T_2	0.57 ± 0.078a	7.7 ±0.049a	0.507 ±0.052a	0.042 ±0.0018a	3.28 ±0.0605a	81.583 ±0.0080a	0.756 ±0.0318a
T_3	0.55 ±0.032a	7.9 ±0.021a	0.578 ±0.077a	0.049 ±0.0036a	3.534 ±0.0087a	81.615 ±0.0086a	0.854 ±0.0343a
T_4	0.56 ±0.083a	7.7 ±0.069a	0.667 ±0.061a	0.057 ±0.0087a	3.565 ±0.0007a	81.666 ±0.0133a	0.941 ±0.0262a
T_5	0.39 ±0.058a	7.7 ± 0.003a	0.729 ±0.064a	0.065 ±0.0155a	3.588 ±0.0051a	81.693 ± 0.0043a	0.991 ± 0.0043a

Table 1 presented the soil characteristic such as soil EC (dsm^{-1}), pH, Organic matter (%), Nitrogen (%), Phosphorous (mgkg^{-1}), Potassium (mgkg^{-1}), and Zinc (mgkg^{-1}), presented data in triplicate with standard error (±) the same lowercase letters (a) indicate non-significant (p<0.05), whereas the variable rates of zinc sulfate fertilizer were T_0=control, T_1=4.5, T_2=9.5, T_3=14.5, T_4=19.5, and T_5=24.5kgha^{-1}

Impact of zinc sulfate fertilization on morphological characteristics of plant

Figure 1 presents the analysis results of the growth components and various rates of Zinc sulfate, the results revealed significant (p<0.05) differences among the treatments, the growth components included plant height, leaf length, pedicel length, and spike length The mean maximum and a significant (p<0.05) difference was recorded in T_5 (75.8±0.87, 13.31±0.20, 35.23±0.60, 10.92±0.032) compared to Control T_0 (60.4±0.53, 6.90±0.47, 26.96±0.77, 7.50±0.41). In-contrast T_0 and T_1 (60.4±0.53, 6.90±0.47, 26.96±0.77, 7.50±0.41 and 70.2±0.58, 8.33±0.22, 32.13±1.015, 9.13±0.37) showed non-significant ($p<0.05$) results compared to T_2, T_3, T_4, and T_5 respectively. Furthermore; compared to T_1, T_4, and T_5 results were significantly ($p<0.05$) different among T_0, T_2, and T_3 (Figure 1).

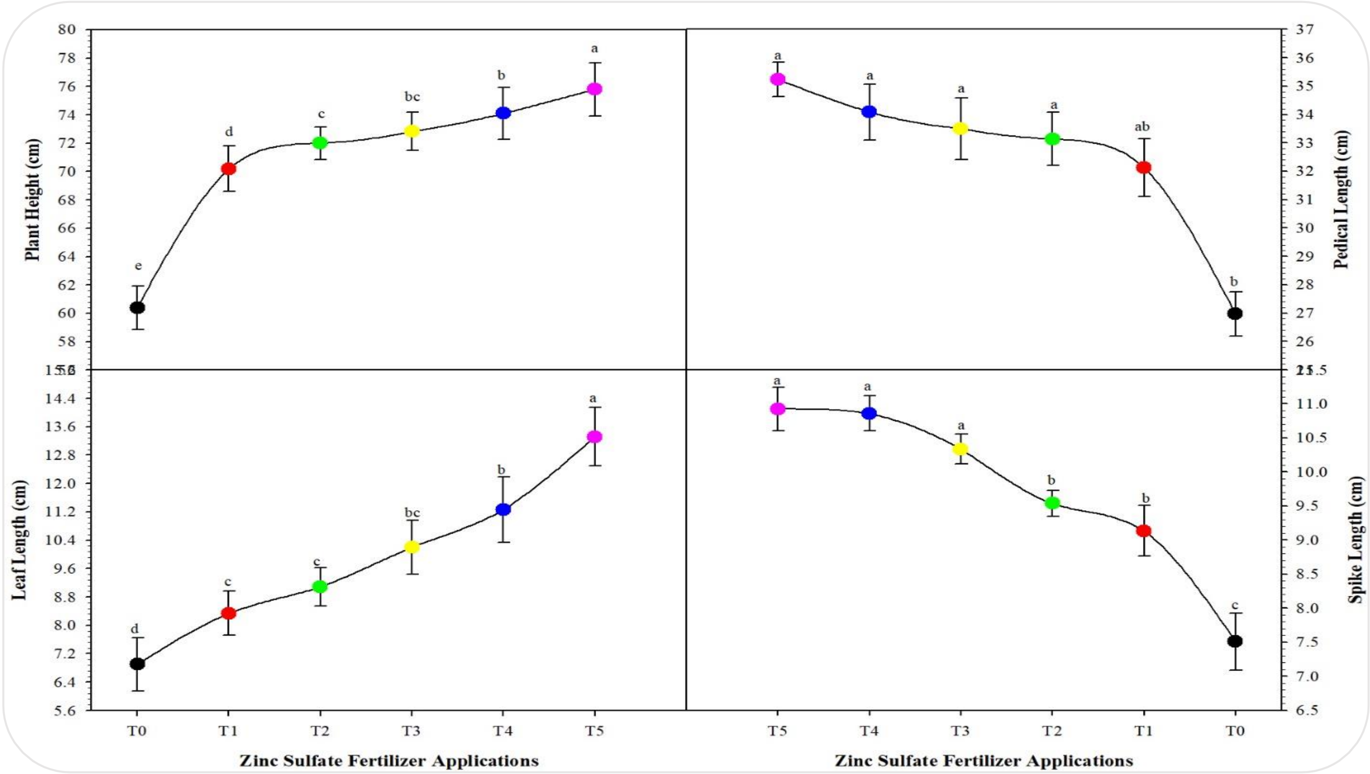

Figure 1. Plant height (cm), spike length (cm) pedicel length (cm), and Leaf area (cm) mean of triplicate with standard errors (±) among the growth components and variable rates of zinc sulfate fertilizer (T_0=control, T_1=4.5, T_2=9.5, T_3=14.5, T_4=19.5, and T_5=24.5kgha^{-1}), the different lowercase letters (a, b, c) indicate significantly different ($p<0.05$).

Impact of zinc sulfate fertilization on biological and gain yield

The analysis results of the influence of different applications of $ZnSO^{-4}$ on biological yield (kgha^{-1}), grain yield (kgha^{-1}), grain weightspike^{-1} (g), and grain weight (g) are presented in (Figure 2). The mean maximum of biological, grain yield, grain weight spike$^{-1,}$ and grain weight were recorded in T_5 (18018.33±820.63, 4233.33±121.02, 45.69±2.038 and 3.23±0.28) followed by T_4 (17219.67±661.41, 4000.00±158.13, 43.10±1.487 and 3.09±0.21) Figure 2. While minimum was recorded in T_0 (8675.660±228.92, 2863.33±146.99, 26.33±0.316 and 1.55±0.22) followed by T_1 (11458.33±476.12, 3446.66±162.41, 37.85±2.020 and 2.56±0.14) (Figure 2). In a comparison of T_0 and T_1 a minor difference among the treatments and a non-significant ($p<0.05$) difference were noted, while; compared to T_0 among T_3, T_4, and T_5 the results were significantly ($p<0.05$) different Figure 2. The observation of biological and grain yield mostly indicated that the increased application of $ZnSO^{-4}$ fertilization could increase the biological yield, grain weight spike^{-1}, and grain yield (Figure 2).

Impact of zinc sulfate fertilization on fertile tillers formation

Formation of fertile tillers (m^2) is the key component of crop productivity, analysis results of fertile tillers formation are presented (Figure 3) and indicate that the combined application of Zn and N has a significant effect on fertile tiller formations. Zn and N fertilization 24.5 and 70 kgha^{-1} was recorded the maximum (11.03±1.38) fertile tillers compared T_0, T_1, T_2, T_3 and T_4 (3.86±0.09, 6.51±1.35, 8.66±0.64, 9.25±0.58 and 10.4±0.63). While; in-comparison of T_4 and T_5 results was non-significant ($p<0.05$). Most findings of our study indicated fertile tiller formations increased as Zn fertilizer application increased (Figure 3).

Zn and N concentration in plant

Plant analysis results of Zn mgkg^{-1} and N% are presented in (Figure 4). The findings of N and Zn concentration in plant material indicated that the mean maximum of both Zn mgkg^{-1} and N% were recorded in T_5 (0.984±0.006 and 1.74±0.035) compared to T_0, T_1, T_2, T_3 and T_4 (3.86±0.09, 6.51±1.35, 8.66±0.64, 9.25±0.58 and 10.4±0.63) respectively, and showed a significant ($p<0.05$) differences among the treatments, whereas mean minimum was noted in T_1 (3.86±0.09) compared to all others (Figure 4). Additionally; the comparison of T_2 and T_3 showed minor differences with non-significant (p<0.05) Figure 4.

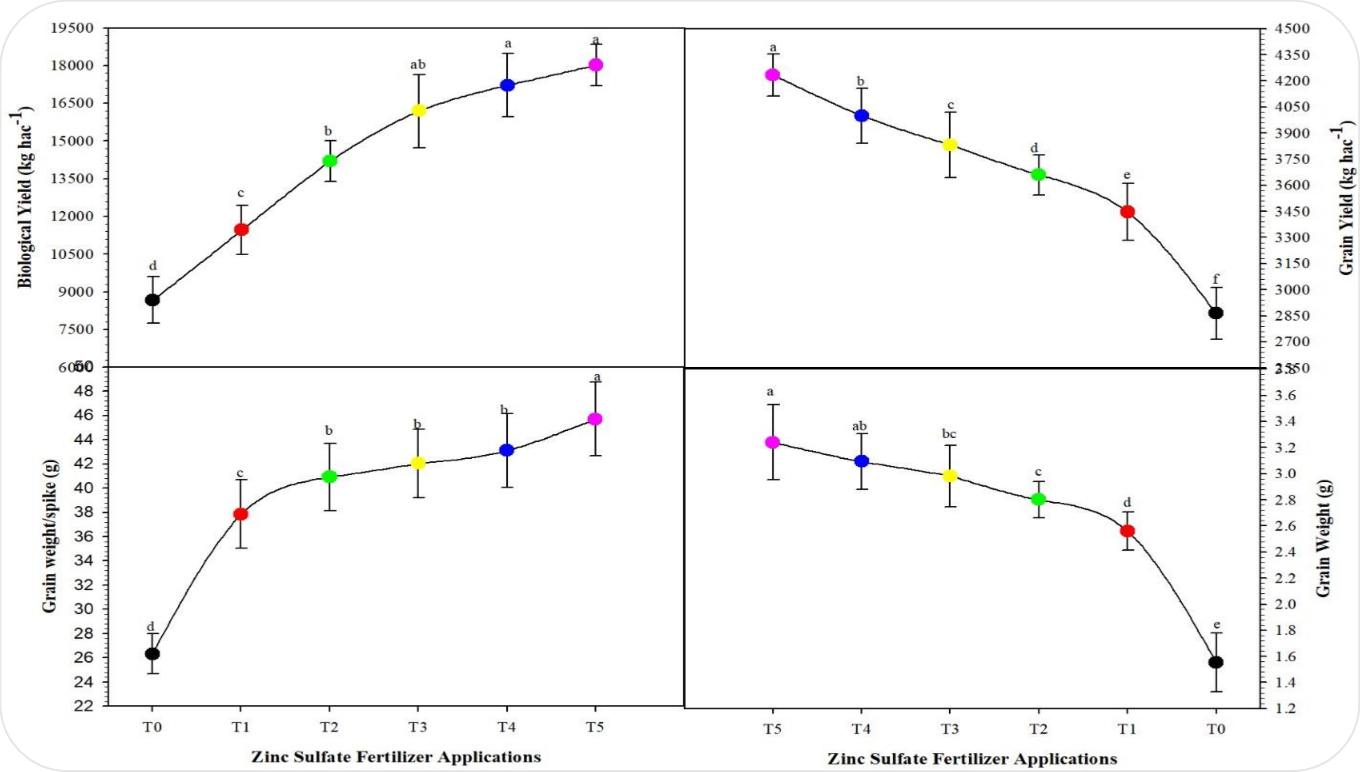

Figure 2. Grain weight/spike (g), Biological yield (kgha^{-1}), Grain weight (g), and grain yield (kgha^{-1}) mean of triplicate with standard (±) errors among the variable rates of zinc sulfate fertilizer (T_0=control, T_1=4.5, T_2=9.5, T_3=14.5, T_4=19.5, and T_5=24.5 kgha^{-1}), the different lowercase letters (a, b, c) indicate significantly different (p<0.05).

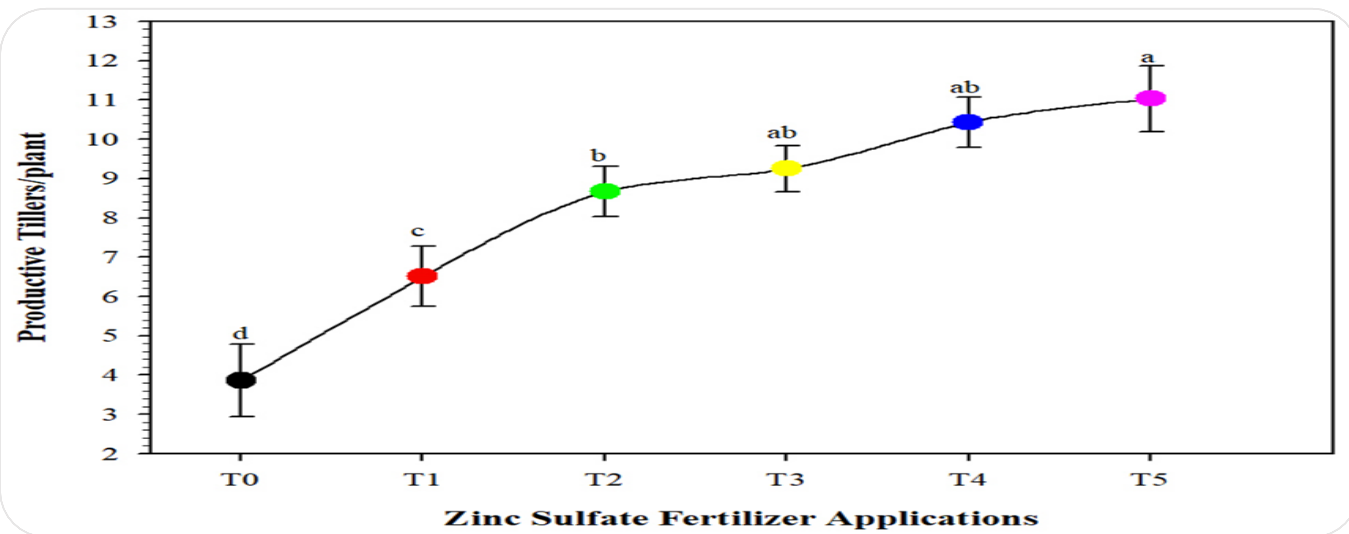

Figure 3. Formation of Productive Tillers/plant mean of triplicate with standard errors (±) among the variable rates of zinc sulfate fertilizer (T_0=control, T_1=4.5, T_2=9.5, T_3=14.5, T_4=19.5, and T_5=24.5kgha^{-1}) the different lowercase letters (a, b, c) indicate significantly different (p<0.05).

Correlation Matrix among soil characteristics, growth, and yield attributes:

The analysis results of the co-relation matrix triangle are presented in Figure 5, and showed a positive highly significant correlation among soil organic matter, total N, available phosphorous, Potassium, and available. The Zn and N concentrations in plants showed a positive significance with growth and yield attributes (Figure 5). Likewise; Zn fertilization was positive and highly significant with growth components such as plant height, leaf length, pedicle length, and spike length. Available zinc, phosphorous, and potassium were highly significantly correlated with biological and grain yield attributes (Figure 5). The negative correlation was recorded in soil pH with soil organic matter, total nitrogen, available phosphorous, potassium, zinc, growth components, and biological and grain yield (Figure 5), and the non-significant was recorded among EC dsm^{-1} and soil organic matter, total nitrogen, available phosphorous, potassium, zinc, growth components and biological and grain yield (Figure 5).

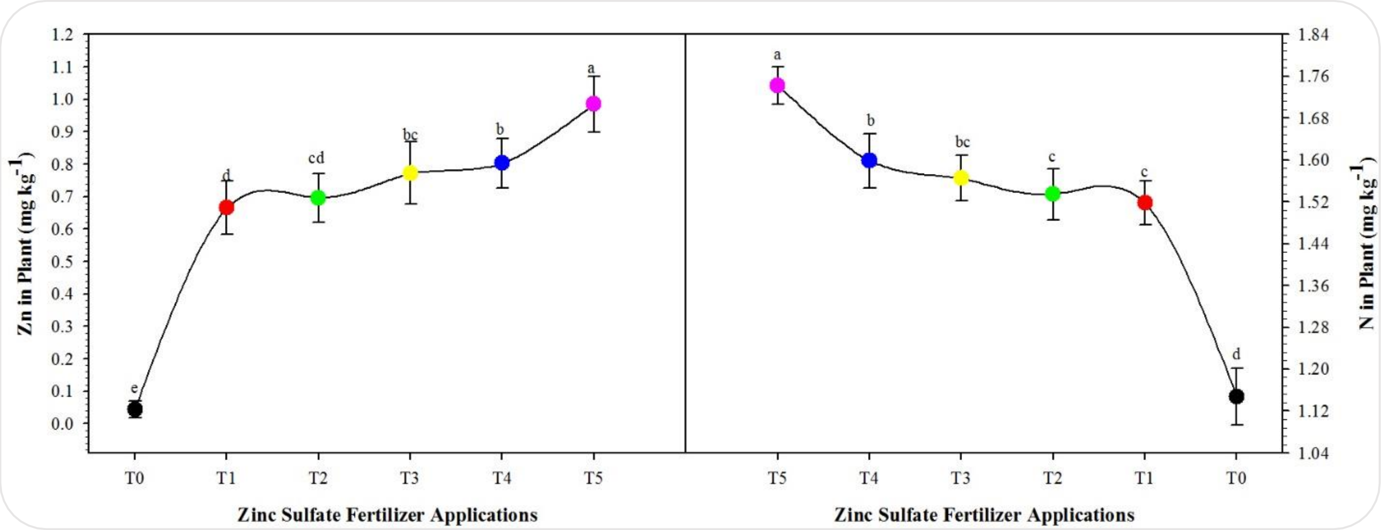

Figure 4. Zn (Zinc) and N (Nitrogen) content in wheat plant mean of triplicate with standard (±) of both Zn and N (mg kg^{-1}), the different lowercase letters (a, b, c) indicate significantly different ($p<0.05$) among the variable rates of zinc sulfate fertilizer (T_0=control, T_1=4.5, T_2=9.5, T_3=14.5, T_4=19.5, and T_5=24.5kgha^{-1}).

PH	*PH*																	
SL	0.96*	*SL*																
GY	0.96*	0.98*	*GY*															
PL	0.99*	0.96*	0.97*	*PL*														
BY	0.92*	0.98*	0.981	0.92*	*BY*													
G/S	0.99*	0.96*	0.97*	0.99*	0.94*	*G/S*												
LA	0.85*	0.92*	0.95*	0.86*	0.94*	0.86*	*LA*											
PT	0.95*	0.98*	0.98*	0.95*	0.99*	0.96*	0.93*	*PT*										
GW/S	0.99*	0.97*	0.97*	0.99*	0.95*	0.99*	0.87*	0.97*	*GW/S*									
NP	0.98*	0.94*	0.96*	0.98*	0.90*	0.98*	0.88*	0.93*	0.97*	*NP*								
ZnP	0.99*	0.94*	0.96*	0.99*	0.90*	0.99*	0.86*	0.93*	0.98*	0.99*	*ZnS*							
SOM	0.93*	0.98*	0.99*	0.93*	0.99*	0.94*	0.96*	0.99*	0.94*	0.92*	0.91*	*SOM*						
NS	0.96*	0.98*	0.99*	0.96*	0.97*	0.96*	0.96*	0.98*	0.97*	0.96*	0.95*	0.98*	*NS*					
PS	0.96*	0.97*	0.98*	0.96*	0.97*	0.97*	0.90*	0.99*	0.97*	0.93*	0.94*	0.97*	0.96*	*PS*				
KS	0.99*	0.97*	0.97*	0.99*	0.94*	0.99*	0.87*	0.96*	0.99*	0.98*	0.98*	0.95*	0.97*	0.97*	*KS*			
ZnS	0.95*	0.99*	0.99*	0.95*	0.98*	0.96*	0.95*	0.99*	0.97*	0.94*	0.94*	0.99*	0.99*	0.97*	0.97*	*ZnS*		
EC	0.12	0.14	0.05	0.11	0.18	0.13	-0.14	0.18	0.16	-0.03	0.03	0.08	0.01	0.22	0.13	0.09	*EC*	
	-0.67*	-0.67*	-0.68*	-0.67*	-0.68*	-0.67*	-0.61*	-0.74*	-0.673	-0.62*	-0.61*	-0.70*	-0.68*	-0.75*	-0.69*	-0.68*	-0.36	*pH*

Figure 5. Correlation Matrix among various zinc sulfate fertilization, soil characteristics, growth, and yield attributes, PH (plant height), SL (spike length), GY (grain yield), PL (Pedicel Length), BY (biological yield), G/S (grain/spike), LA (leaf area), GW/S (grain weight/spike), NP (nitrogen in plant), ZnP (zinc in plant), SOM (soil organic matter), NS (nitrogen in soil), PS (phosphorus in soil), KS (potassium in soil), ZnS (zinc in soil), EC (electrical Conductivity), and pH, mostly correlation matrix of various parameters were positive co-related significant ($p<0.05$), pH was negative significant and EC was non-significant ($p<0.05$).

DISCUSSION

Plants absorb zinc in divalent ionic form (Zn^{2+}), and chelate form. Fertilizer zinc sulfate contains 30% Zn and 60% S easily absorbed by plants and showed a positive significant effect on the growth and yield component of the Faisalabad wheat variety cultivated in the hilly areas of Uthal Balochistan. The findings of this study showed increasing application of $ZnSO^-_4$ led to improved plant height (cm), leaf length (cm), spike length (cm), and pedicel length (cm) were significantly increased compared to the control, similarly Shoja et al. (2018), who conducted his research on Zn fertilization on rapeseed, and reported the increased application of Zn improved the growth and grain yield components of rapeseed. Some past studies explain that a small quantity of Zn concentrations plays several roles in plants such as seedling vigor, plant, and seed grain membrane, sugar formation, improvement drought and heat stress, and the metal component of enzymes (Ferrari et al., 2021; Singh et al., 2018) proteins, lipids and co-factor of growth hormones, accordingly play an important role in biological and grain yield of wheat (Hassan et al., 2019; Sattar et al., 2022). This positive influence on wheat might be the interaction of Zn concentrations in the soil solutions that play a major in the formation of chlorophyll and are involved in carbon metabolism (Hera et al., 2018; Sultana et al., 2016). Such co-related observations were also revealed in this study that the increased rate of zinc sulfate increased tiller formation, spike length, grain weight biological yield, and grain yield have increased with increasing Zn fertilization that showed a positive interaction of Zn and N applications (Figure 1, 2, 3, and 4). Moreover; Zn is an integral component of various biomolecules and beneficial for crop productivity and quality, however; an insufficient amount of Zn declines the growth of plants and reduces the quality of seed (Rehman et al., 2018; Suganya et al., 2020). Singh et al. (2018) conducted research on rice with the application of Zinc sulfate, which revealed that at 0-6 $kgha^{-1}$ increase in grain and biological yield of rice compared to control, the finding of this study also indicated that at the rate of 24.5$kgha^{-1}$ of $ZnSO^-_4$ increases 20% fertile tillers, $grainspike^{-1}$, grain weight (g) grain yield ($kgha^{-1}$) and biological yield ($kgha^{-1}$) of wheat (Figure 1, 2, 3 and 4) compared to control. Adeel et al. (2024) reported that higher plant leaf Zn concentration should accumulate towards higher assimilation of photosynthesis from the source to sink resulting in higher crop yield.

Soil is the medium for plant growth, the required nutrient uptake by plants from soil solution through plant roots and transported to other parts of the plant (Gupta et al., 2016), moreover; the combined application of Zn and N improves the growth of plant, this might help to change pH level in soil solution and increase N uptake (Dhaliwal et al., 2022; Hassan et al., 2019; Shehzadi et al., 2024). Hafeez et al. (2021) conducted their research on Zn and Fe-based fertilization which showed the increased application of Zn fertilization has a positive interaction among the growth and yield of wheat cultivars. Similarly, the findings of this study indicated the increased level of Zn fertilization effect on the availability of both Zn and N concentrations in plants compared to control, and ultimately impact on the growth and yield component of Faisalabad wheat (Figure 1, 2, 3 and 4). Furthermore; Dawar et al. (2021) conducted their research study on $ZnSO^-_4$ and reported that increased application of $ZnSO^-_4$ improved plant growth and higher plant biomass, photosynthesis and resulting in maximum crop yield. Similar findings were recorded in this study that $ZnSO^-_4$ at the rate of 24.5 $kgha^{-1}$ affects the plant growth and yield component compared to other treatments (Figures 1, 2, 3, and 4). Additionally; the co-relation matrix (Figure 5) of this indicated a highly positive significant interaction among the various soil and plant properties similar findings were recorded by Shehzadi et al. (2024) and reported the positive interaction between Zn and N content in soil and plant. Conclusively; the finding of this study suggested that $ZnSO^-_4$ at 24.5$kgha^{-1}$ would improve the soil properties, plant growth component, and yield attribute of wheat (Figures 1, 2, 3, and 4).

CONCLUSION

The variable rate of zinc sulfate remarkably increased the growth of wheat cultivated in hilly areas of Uthal, Balochistan Pakistan. The positive interaction was recorded among the N, P, and K nutrients and ultimately increased morphological growth characteristics of the wheat plant such as plant height, leaf length, spike length, and pedicle length. Similarly improved yield components of wheat formation of fertile $tillerplant^{-1}$, biological yield, $grainspike^{-1}$, grain weight, and grain yield. Conclusively; the variable application of zinc sulfate increased Zn concentration in plants and increased nutritional values of human health. Future studies a long-term field research experiments could be conducted grounded on the interaction of macro-nutrients and micro-nutrients with the combined application of zinc under different climatic conditions to estimate the impact of different levels of zinc sulfate in different cereal, fiber, and vegetable crops cultivated in Pakistan.

AUTHOR CONTRIBUTIONS

Khalid Hameed Mengal- Conducted field experiments and compiled the initial draft of the article, Shahmir Ali Planned the research study and overall supervised field and lab experiments, Muneer Ahmed Rodeni-filed work, Kashif Ali Kubar- reviewed the article, Punhoon Khan Korai-analysis data, Siraj Ahmed-lab work, Shabir Ahmed-organized graphical data, Bilal Ahmed Ababaki-edit revision of review article, Sami ullah-lab work, Sher Jan- field work, Abdullah Raisani-lab work, Zain ul abidin kasi-organized data and Javed Ahmed Mengal-field and lab work.

COMPETING OF INTEREST

Authors have no conflict of interest of interest exists and have no financial arrangement with any company whose product figures prominently in the submitted manuscript or with a company making a competing product.

REFERENCES

Adeel, M.A., Hussain, S., Basit, A., Hussain, M.B., Aon, M., 2024. Biofortification of wheat in salt-affected soil through seed priming and soil application of zinc. Journal of Trace Elements and Minerals 8, 100159.

Ahmed, S., Kalhoro, S.A., Ahmed, B., Sarfaraz, Q., Rodeni, M.A., Hameed, K., Ullah, S., 2024. Impact of Humic Acid on the Morphological Components and Growth Parameters of Wheat (Triticum Aestivum L.) Under Dry Climate of Uthal. Journal of Applied Research in Plant Sciences 5, 226-236.

Azeem, A., Ul-Allah, S., Azeem, F., Naeem, M., Sattar, A., Ijaz, M., Sher, A., 2023. Effect of foliar applied zinc sulphate on phenotypic variability, association and heritability of yield and zinc biofortification related traits of wheat genotypes. Heliyon 9.

Corpas, F.J., Palma, J.M., 2020. H2S signaling in plants and applications in agriculture. Journal of Advanced Research 24, 131-137.

Dawar, K., Khan, N., Fahad, S., Alam, S.S., Khan, S., Mian, I.A., Akbar, W.A., 2021. Effect of sulfur and zinc nutrition on yield and uptake by wheat. Journal of Plant Growth Regulation, 1-9.

Dhaliwal, S.S., Sharma, V., Shukla, A.K., Verma, V., Kaur, M., Shivay, Y.S., Nisar, S., Gaber, A., Brestic, M., Barek, V., 2022. Biofortification—A frontier novel approach to enrich micronutrients in field crops to encounter the nutritional security. Molecules 27, 1340.

Estefan, G., 2013. Methods of soil, plant, and water analysis: a manual for the West Asia and North Africa region. International Center for Agricultural Research in the Dry Areas (ICARDA).

Faizan, M., Bhat, J.A., Chen, C., Alyemeni, M.N., Wijaya, L., Ahmad, P., Yu, F., 2021. Zinc oxide nanoparticles (ZnO-NPs) induce salt tolerance by improving the antioxidant system and photosynthetic machinery in tomato. Plant Physiology and Biochemistry 161, 122-130.

Ferrari, M., Dal Cortivo, C., Panozzo, A., Barion, G., Visioli, G., Giannelli, G., Vamerali, T., 2021. Comparing soil vs. foliar nitrogen supply of the whole fertilizer dose in common wheat. Agronomy 11, 2138.

Gatto, A., Loewenstein, W., Sadik-Zada, E.R., 2021. An extensive data set on energy, economy, environmental pollution and institutional quality in the petroleum-reliant developing and transition economies. Data in Brief 35, 106766.

Guerrini, L., Napoli, M., Mancini, M., Masella, P., Cappelli, A., Parenti, A., Orlandini, S., 2020. Wheat grain composition, dough rheology and bread quality as affected by nitrogen and sulfur fertilization and seeding density. Agronomy 10, 233.

Gupta, N., Ram, H., Kumar, B., 2016. Mechanism of zinc absorption in plants: uptake, transport, translocation and accumulation. Reviews in Environmental Science and Bio/Technology 15, 89-109.

Hafeez, M.B., Ramzan, Y., Khan, S., Ibrar, D., Bashir, S., Zahra, N., Rashid, N., Nadeem, M., Rahman, S.u., Shair, H., 2021. Application of zinc and iron-based fertilizers improves the growth attributes, productivity, and grain quality of two wheat (Triticum aestivum) cultivars. Frontiers in Nutrition 8, 779595.

Haider, S.A., Naqvi, S.R., Akram, T., Umar, G.A., Shahzad, A., Sial, M.R., Khaliq, S., Kamran, M., 2019. LSTM neural network based forecasting model for wheat production in Pakistan. Agronomy 9, 72.

Hassan, M.U., Chattha, M.U., Ullah, A., Khan, I., Qadeer, A., Aamer, M., Khan, A.U., Nadeem, F., Khan, T.A., 2019. Agronomic biofortification to improve productivity and grain Zn concentration of bread wheat.

Hera, M.H.R., Hossain, M., Paul, A.K., 2018. Effect of foliar zinc spray on growth and yield of heat tolerant wheat under water stress. Journal of Biological and Environmental Engineering 1, 10-16.

Jackson, M.L., 2005. Soil chemical analysis: advanced course: a manual of methods useful for instruction and research in soil chemistry, physical chemistry of soils, soil fertility, and soil genesis. UW-Madison Libraries parallel press.

Jalal, A., Galindo, F.S., Freitas, L.A., da Silva Oliveira, C.E., de Lima, B.H., Pereira, Í.T., Ferraz, G.F., de Souza, J.S., da Costa, K.N., Nogueira, T.A.R., 2022. Yield, zinc efficiencies and biofortification of wheat with zinc sulfate application in soil and foliar nanozinc fertilisation. Crop and Pasture Science.

Joy, E.J., Ahmad, W., Zia, M.H., Kumssa, D.B., Young, S.D., Ander, E.L., Watts, M.J., Stein, A.J., Broadley, M.R., 2017. Valuing increased zinc (Zn) fertiliser-use in Pakistan. Plant and Soil 411, 139-150.

Nguemezi, C., Tematio, P., Yemefack, M., Tsozue, D., Silatsa, T., 2020. Soil quality and soil fertility status in major soil groups at the Tombel area, South-West Cameroon. Heliyon 6.

Qadir, M., Wang, X., Baloch, A.H., Baloch, I.A., Azeem, M., Imran, M., Saleem, M., 2018. The impact of drought on phenotypic characters of five advance bread wheat genotypes. Pure and Applied Biology 7, 635-642.

Rehman, A., Farooq, M., Naveed, M., Ozturk, L., Nawaz, A., 2018. Pseudomonas-aided zinc application improves the productivity and biofortification of bread wheat. Crop and Pasture Science 69, 659-672.

Sattar, A., Wang, X., Ul-Allah, S., Sher, A., Ijaz, M., Irfan, M., Abbas, T., Hussain, S., Nawaz, F., Al-Hashimi, A., 2022. Foliar application of zinc improves morpho-physiological and antioxidant defense mechanisms, and agronomic grain biofortification of wheat (Triticum aestivum L.) under water stress. Saudi Journal of Biological Sciences 29, 1699-1706.

Sehgal, A., Sita, K., Kumar, J., Kumar, S., Singh, S., Siddique, K.H., Nayyar, H., 2017. Effects of drought, heat and their interaction on the growth, yield and photosynthetic function of lentil (Lens culinaris Medikus) genotypes varying in heat and drought sensitivity. Frontiers in Plant Science 8, 1776.

Shehzadi, N., Mahmood, A., Kaleem, M., Chishti, M.S., Bashir, H., Hashem, A., Abd-Allah, E.F., Shahid, H., Ishtiaq, A., 2024. Zinc and nitrogen mediate the regulation of growth, leading to the upregulation of antioxidant aptitude, physio-biochemical traits, and yield in wheat plants. Scientific Reports 14, 12897.

Shoja, T., Majidian, M., Rabiee, M., 2018. Effects of zinc, boron and sulfur on grain yield, activity of some antioxidant enzymes and fatty acid composition of rapeseed (Brassica napus L.). Acta Agriculturae Slovenica 111, 73-84.

Singh, B.R., Timsina, Y.N., Lind, O.C., Cagno, S., Janssens, K., 2018. Zinc and iron concentration as affected by nitrogen fertilization and their localization in wheat grain. Frontiers in Plant Science 9, 307.

Singh, S., Kaur, J., Ram, H., Singh, J., Kaur, S., 2023. Agronomic bio-fortification of wheat (Triticum aestivum L.) to alleviate zinc deficiency in human being. Reviews in Environmental Science and Bio/Technology 22, 505-526.

Suganya, A., Saravanan, A., Manivannan, N., 2020. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (Zea mays L.) grains: An overview. Communications in Soil Science and Plant Analysis 51, 2001-2021.

Sultana, S., Naser, H.á., Shil, N., Akhter, S., Begum, R., 2016. Effect of foliar application of zinc on yield of wheat grown by avoiding irrigation at different growth stages.

Thapa, D.B., Subedi, M., Yadav, R.P., Joshi, B.P., Adhikari, B.N., Shrestha, K.P., Magar, P.B., Pant, K.R., Gurung, S.B., Ghimire, S., 2022. Variation in grain zinc and iron concentrations, grain yield and associated traits of biofortified bread wheat genotypes in Nepal. Frontiers in Plant Science 13, 881965.

Usmani, M.M., Nawaz, F., Majeed, S., Shehzad, M.A., Ahmad, K.S., Akhtar, G., Aqib, M., Shabbir, R.N., 2020. Sulfate-mediated drought tolerance in maize involves regulation at physiological and biochemical levels. Scientific Reports 10, 1147.

Wahid, M.A., Irshad, M., Irshad, S., Khan, S., Hasnain, Z., Ibrar, D., Khan, A.R., Saleem, M.F., Bashir, S., Alotaibi, S.S., 2022. Nitrogenous fertilizer coated with zinc improves the productivity and grain quality of rice grown under anaerobic conditions. Frontiers in Plant Science 13, 914653.

Walkley, A., Black, I.A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science 37, 29-38.

Wang, X., Li, Q., Pei, Z., Wang, S., 2018. Effects of zinc oxide nanoparticles on the growth, photosynthetic traits, and antioxidative enzymes in tomato plants. Biologia Plantarum 62, 801-808.

Wilson, T.L., Guttieri, M.J., Nelson, N.O., Fritz, A., Tilley, M., 2020. Nitrogen and sulfur effects on hard winter wheat quality and asparagine concentration. Journal of Cereal Science 93, 102969.

Zhu, D.-B., Hu, K.-D., Guo, X.-K., Liu, Y., Hu, L.-Y., Li, Y.-H., Wang, S.-H., Zhang, H., 2015. Sulfur dioxide enhances endogenous hydrogen sulfide accumulation and alleviates oxidative stress induced by aluminum stress in germinating wheat seeds. Oxidative Medicine and Cellular Longevity 2015, 612363.