Egypt. J. Agron. **Vol. 47**, No. 4, pp: 791 - 813 (2025)

Egyptian Journal of Agronomy

http://agro.journals.ekb.eg/

Effect of Zinc Treatments on the Nutrient Contents of some Egyptian and Romanian Wheat

Mohamed M. El-Fouly[1], Alina L. Agapie[2], Marinel N. Horablaga[2], Samir H. Shaaban[1*], Ciprian Buzna[2],Adel B. El-Nasharty[1], Ionut Racz[3] Mohamad F. El-Dahshouri[1], Nicolae Tritean[3], Rozalia Kadar[3] , Huda A. El-Mnadily[1]

*Corresponding author: shashaaban@yahoo.com Orcid ID: /0000-0001-6512-087X

[1]*Department of Fertilization Technology, National Research Centre, 33 El- Bohouth St., (former El- Tahrir St.,) Dokki, Giza, Postal Code: 12622, Egypt*

[2]*Agricultural Research and Development Station Lovrin, Timis County, Romania*

[3]*Agricultural Research and Development Station Turda, Cluj County, Romania*

DURING the winter season of 2019/2020, 2020/2021 and 2021/2022 in Egypt, two locations were representing clay and calcareous soils, where wheat varieties are grown, namely Giza 168, Giza 171 and Gemmeiza 11. These varieties spraying with Zn sulfate 5 g/L during tillering (1) and milk stage (2) and (stage 1 and 2). It was found that the zinc level in flag leaves of Gemmiza 11 and Giza 171 improved as a result of foliar application in the Tillering+ Millk phases. Giza 171 was superior to Giza 168 in the % of zinc in grain and straw. As a result of the effect of increasing the zinc content in the leaves, grains and straw, the content of some other nutrients such as N, P, Ca and Mg were improvement.

In Romania, the experiment was conducted on four varieties: Ciprian, Glosa, Andrada and Padureni. These varieties were treated with zinc sulfate, include soil with 30kg/ha before sowing, seed treated and foliar application with 0.3% solution at different stages. The combination of seed soaking, soil addition, and foliar spraying led to a clearer effect on zinc %, and the varieties differed in the rates of increases with the method of application.

Keywords: Wheat, zinc, leaves, grain, straw.

Introduction

Zinc is an essential micronutrient for biological system. Its role in biological systems is in protein synthesis and in metabolism. Zinc enters in the human or animal body via food of plant and animal origin. Zinc deficiency in food can cause various maladies. In order to enrich the food of vegetal origin with Zn, the biofortification is practiced with the chemical elements, which is in the deficiency level. The most representative case is the zinc deficiency recorded in wheat and other crops. Zinc deficiency is a well-documented problem in food crops, causing decreased crop yields and nutritional quality. Generally, the regions in the world with Zn-deficient soils are also characterized by widespread Zn deficiency in humans. Recent estimates indicate that nearly half of world population suffers from Zn deficiency. Cereal crops play an important role in satisfying daily calorie intake in developing world, but they are inherently very low in Zn concentrations in grain, particularly when grown on Zn-deficient soils. The reliance on cereal-based diets may induce Zn deficiency-related health problems in humans, such as impairments in physical development, immune system and brain function. (Cakmak 2008). By foliar Zn application such marked increases in grain Zn by foliar Zn application would have important contributions to improving dietary intake of Zn by human beings, and harvesting more grain zinc of wheat for decreasing the deaths of children and human health (Brown et al. 2001, Chen et al., 2017, Cakmak and Kutman, 2018.). Almost in all experiments conducted in seven countries by Zou et al., 2012, the increments in grain Zn associated with only foliar Zn spray was more than 10 mg Zn kg^{-1} grain.

It is obvious that the targeted levels of Zn in wheat grain for a better human nutrition can be achieved substantially through soil and foliar Zn application (Bharti et al. 2013, Dhaliwal et al. 2019 and Das et al. 2020). Application of foliar Zn fertilizers represents a short-term solution to the problem, knowledge that plants emerging from high Zn-seeds usually have better seedling vigor and field establishment (Cakmak 2008). Under unfavorable

*Corresponding author email: shashaaban@yahoo.com - Orcid ID: /0000-0001-6512-087X
Received: 28/09/2024; Accepted: 20/08/2025
DOI: 10.21608/agro.2025.318891.1521

field conditions, levels of grain Zn are mainly affected from the pool of Zn in vegetative tissue and its remobilization into grain. As reported previously, stem and leaf tissues represent important Zn reserves which are effectively utilized for Zn deposition into grains (Haslett et al. 2001; Kutman et al 2010; Pearson and Rengel 1994).

Therefore, keeping high amounts of Zn in vegetative tissue, for example by foliar Zn application, can contribute more to grain Zn concentration as shown in the present and previous studies (Cakmak 2009, Cakmak et al. 2010, Kutman et al. 2010, Zhang et al. 2012, Niyigaba et al., 2019, Adebayo, et al, 2023, El-Fouly et al, 2023 and El-Saady et al., 2023). Because Egypt imports large quantities of wheat from Romania, an Egyptian-Romanian scientific collaboration was proposed on the subject of zinc enrichment of wheat grains.

In both cases, this leads to higher Zn intake in Egyptian diet and help improving health conditions of the population. Increasing Zn content leads to increasing the quality of wheat. The bio fortified Romanian grains exported to Egypt will have higher health and economic value. Consuming wheat with higher Zn content will improve the Zn intake by humans and reduce the risk of having Zn deficiency in the population.

This study aimed to investigate and explore the practical possibilities of increasing the zinc content in cereals of some Egyptian and Romanian wheat varieties exported to Egypt. As well as studying the effect of zinc spraying on the concentrations of the rest of the elements.

Material and Methods

Field experiments in Egypt

Different Egyptian wheat varieties were used in the study. Three varieties of wheat were tested in field in Egypt. These varieties were treated with Zn sulphate in the field during two phases tillering/stem extension (1) and milk stage (2). Treatments were as follows for each variety:

1. Without Zn
2. With Zn (stage 1)
3. With Zn (stage 2)
4. With Zn (stage 1 and 2)

In Egypt, two locations were selected representing clay and calcareous soils, where the common wheat varieties are grown, namely Giza 168, Giza 171 and Gemmeiza 11.

The study was carried out during the winter season of 2019/2020, 2020/2021 and 2021/2022 to study effect of Zn sulfate (as a source of Zn) on nutrient contents of the two wheat varieties in the farmer's field in Oraby Village Mariut sector, Alexandria,
Egypt (located between latitude 30°58'47"N and longitude 29°48'38"E), representing calcareous soils and in the farmer's field in the Nahia site of the Kerdasa District, Giza governorate, representing clay soils. A representative soil sample was taken from 0-30 cm depth before planting.

A sample was taken from the seeds before planting and their zinc content was estimated.

Soil preparation and cultivation:

Soil was ploughed using a chisel plough, leveled by wooden leveler and divided into experimental units with three replicates.

Experiments Design: The experimental design was randomized complete block design (RCBD) with three replicates. Plot area was 10.5 m^2 (3.5 m long and 3 m wide).

Chemical analysis:

Soil analysis:-

Before planting, a representative soil sample was taken before sowing to test physical and chemical properties, during two winter seasons of 2019/2020 and 2020/2021.

Soil of experimental sites was analyzed for the following chemical and physical properties:

Texture–pH–EC-$CaCO_3$ –OM%–P–K–Ca-Mg–Fe–Mn–Zn-Cu (Chapman and Pratt, 1978).

Plant analysis:

Ten plants of each: shoot system, flag leaf and plants (straw and grains) of random samples from each plot in three replication cutting at three stages namely: shooting, flag leaf and at harvest respectively, to be analyzed for nutrients content. Shoot system, flag leaves, straw and grains were washed in sequence with tap water, 0.01 N HCl – acidified bidistilled water and bidistilled water, respectively, and then dried in a ventilated oven at 70 C0 till constant weight was obtained. The plant samples were ground in stainless steel mill with 0.5 mm sieve and kept in plastic containers for analysis. The sample (1.0 g) was determined of dry-ashing in a muffle furnace based on the method described by Jones, Jr. et al. (1991).

Plants of different plots/treatments were collected at the phase of tillering, stem extension (only the aerial part of the plant) and analysed the following chemical elements: N, P, K, Ca, Mg, Fe, Mn, Cu, Zn (Chapman and Pratt, 1978).

Data recorded:

Contents of N, P, K, Ca, Mg, Fe, Mn, Cu and Zn were recorded for Leaves of shoot, flag leaf and Grains, straw at maturity.

Statistical Analysis:

The obtained data were statistically analyzed using COSTAT program and L.S.D. value at the probability levels of 5% and calculated according to Gomez and Gomez (1984).

Field experiments in Romania

The soil analyses taken indicate a very low content of the soil in zinc, 0.6 mg/kg. (2019-2020) and 1.8 mg/kg, (2020-2021), falls below the critical threshold of 2.0 mg/kg DTPA-extractable Zn (Alloway, 2009).

The chemical fertilizer used was zinc sulfate, with an active substance content of Zn of 25.4 %.
Ground treatment, 30 kg Zn/ha was applied before sowing. For seed treatment and foliar administration, the concentration of the prepared solution was 0.3%.
The experimental device established at SCDA Lovrin, in the agricultural years 2019-2020, 2020-2021 includes the following factors:
Factor A:
a1- untreated seed;
a2–seed treated with zinc susphate – 0.3% solution.
Factor B:
b1 – Ciprian variety;
b2 - Glosa variety;
b3 - Andrada variety; Dacic variety;
b4 – Pădureni variety.
Factor C:
c1 – untreated control;
c2 – ground treatment with zinc sulphate 30 kg/ha:
c3–foliar treatment at the end of twinning;
c4–foliar treatment in the bellows phase;
c5–foliar treatment in the milk-wax phase.
In order to evaluate the absorption and accumulation of zinc, its presence in the soil, the biological material sown, in the green plant was analyzed 20 days after the administration of each treatment, in the standard leaf and in the grain, immediately after harvesting the crop.
The first foliar treatment, which aimed at the end of the plant twinning period, was administered on 20.03.2020.

Results and Discussion
Egyptian trials
1. Soil testing and irrigation water:
Results of the first season for Location 1 (2019/2020)
1. Soil testing and irrigation water:
Table 1 reveals critical limitations in the Mariout site's calcareous soil:
High pH (8.4) and $CaCO_3$ (28.6%) led to immobilize micronutrients, particularly Zn, through Zn precipitation as $ZnCO_3$ (Lindsay,1979) and adsorption onto $CaCO_3$ surface (Alloway, 2009) Also, low organic matter (1.5%) reduces chelation of Zn and Fe, exacerbating deficiency (Ryan et al., 2013) and Salinity (EC 3.4 dS/m) and Na^+ (842 mg/kg) competes with K^+ and Zn^{2+} uptake (Tavakkoli et al., 2010). On the other hand, zinc (0.85 mg/kg) was below critical level (1.0 mg/kg DTPA-extractable Zn; Cakmak, 2008).
2. Irrigation Water
The irrigation water analyzes also showed a high salinity of the water, reaching 6 dS/m., exceeds FAO wheat tolerance threshold (4 dS/m); Ayers & Westcot, 1985).

TABLE 1. Soil test of Mariout site before sowing (0-30cm depth).

Character		Nutrient content (mg/Kg)	
Texture: calcareous		Available – N	508.00 L
pH	8.4 H	Available – P	19.00 M
E.C dS/m	3.4 VH	Available - K	260.00 M
$CaCO_3$ %	28.6 H	Available - Ca	493.00 L
O.M %	1.5 L	Available - Na	842.00 VH
		Available - Fe	3.63 VL
		Available - Mn	1.06 VL
		Available - Zn	0.85 L
		Available – Cu	0.70 L

VL= Very Low, L = Low, M = Moderate, H = High, VH = Very High (Ankerman and Large, 1974)

Table 2 and 3 showed that there is an increase in the concentration of zinc in grains and straw of wheat as a result of spraying with zinc sulphate in different growth stages, especially spraying at tillering & milky stages, compared to the control. This agrees with what Afshar et al. 2020 found, that the application of Zn at both heading and flowering, grain Zn concentration reached 44.3 and 52.4 mg kg^{-1}. It was also showed that the Giza 171 variety was superior to the Giza 168 variety in the percentage of zinc increase in grain and straw where Grains: 60.33 ppm (Giza 171) vs 36.33 ppm control (66% increase) and Straw: 31.70 ppm (Giza 171) vs 20.70 ppm control (53% increase) The improvement may be attributed to active branching (Çakmak, 2008) and grain zinc loading (Öztürk et al., 2006). Achieving grain zinc contents above 50 ppm met the WHO 2020 targets.

TABLE 2. Effect of foliar zinc spraying on zinc content in wheat grains grown on location1

Variety	Treatment			
	Control (water spray)	At Tillering	At Milky Stage	At Tillering & Milky Stage
Giza 171	36.33	49.33	54.00	60.33
Giza 168	34.67	47.33	49.33	54.33

TABLE 3. Effect of foliar zinc spraying on zinc content, in wheat straw grown on location 1.

Variety	Treatment			
	Control (water spray)	At Tillering	At Milky Stage	At Tillering & Milky Stage
Giza 171	20.70	26.33	29.33	31.70
Giza 168	19.33	22.00	26.00	28.33

Results of the second season for Location 1 (2020/2021)

Table 4 showed a significant increase in potassium (K) and calcium (Ca) concentrations in different parts of the plant (stem, flag leaves, and straw) for both cultivars (Giza 168 and Giza 171) when sprayed with zinc sulfate, especially during the tillering & milky stages or both. Phosphorus (P) and magnesium (Mg) concentrations also improved in the flag leaves and straw, with Giza 171 showing a stronger response than Giza 168. Zinc is known to play a crucial role in activating enzymes involved in plant metabolism, such as phosphatases, which enhance phosphorus uptake (Marschner, 2012). The synergistic effect between zinc and potassium may be attributed to zinc's role in enhancing the activity of potassium channels in cell membranes (Cakmak, 2008), while the increased calcium uptake may be attributed to enhanced root uptake of zinc via certain proteins (Broadley et al., 2012). The superior response of Giza 171 may stem from its genetic competence in zinc uptake and transport, which promotes better absorption of the macronutrient (Genk et al., 2007).

TABLE 4. Effect of foliar spray applications with zinc sulfate at different stages on macronutrients contents.

Treatment		**%**				
Variety	**Stages of zinc spray**	**P**	**K**	**Ca**	**Na**	**Mg**
(shoot after the first spray)						
Giza 168	Control	0.213	1.8	0.37	0.44	0.102
	At Tillering	0.224	2.2	0.51	0.40	0.123
	At Milky Stage	0.216	1.9	0.35	0.40	0.111
	At Tillering & Milky Stage	0.218	2.2	0.49	0.42	0.121
LSD (0.05)		**NS**	**0.28**	**0.10**	**NS**	**NS**
Giza 171	Control	0.215	1.7	0.34	0.40	0.101
	At Tillering	0.231	2.5	0.60	0.39	0.128
	At Milky Stage	0.218	1.8	0.35	0.38	0.113
	At Tillering & Milky Stage	0.226	2.4	0.59	0.39	0.127
LSD (0.05)		**NS**	**0.29**	**0.12**	**NS**	**NS**
(Flag Leaf)						
Giza 168	Control	0.178	1.4	1.2	0.38	0.316
	At Tillering	0.192	1.9	1.5	0.35	0.353
	At Milky Stage	0.180	1.7	1.4	0.37	0.351
	At Tillering & Milky Stage	0.195	2.0	1.6	0.37	0.467
LSD (0.05)		**0.010**	**0.23**	**0.35**	**NS**	**0.027**
Giza 171	Control	0.176	1.5	1.2	0.35	0.303
	At Tillering	0.199	2.1	1.6	0.34	0.387
	At Milky Stage	0.188	2.0	1.5	0.35	0.373
	At Tillering & Milky Stage	0.206	2.2	1.8	0.36	0.485
LSD (0.05)		**0.011**	**0.39**	**0.40**	**NS**	**0.015**
(Straw at harvest)						
Giza 168	Control	0.109	1.2	0.57	0.30	0.38
	At Tillering	0.114	1.7	0.82	0.46	0.38
	At Milky Stage	0.121	1.6	0.75	0.41	0.40
	At Tillering & Milky Stage	0.130	1.9	0.84	0.50	0.45
LSD (0.05)		**0.012**	**0.40**	**0.20**	**0.06**	**0.04**
Giza 171	Control	0.117	1.3	0.56	0.46	0.45
	At Tillering	0.120	1.9	0.95	0.60	0.55
	At Milky Stage	0.128	1.8	0.87	0.49	0.52
	At Tillering & Milky Stage	0.138	2.1	0.92	0.51	0.60
LSD (0.05)		**0.003**	**0.45**	**0.31**	**0.05**	**0.06**

Table 5: showed an increase in the concentration of zinc in the different parts of wheat plants as a result of spraying with zinc sulphate in both varieties Giza 168 and Giza 171, while a slight decrease occurred in the iron, manganese and copper nutrients, perhaps due to the phenomenon of antagonism between zinc and iron (Fe) and manganese (Mn), while copper (Cu) remained stable in most cases.

The decline in Fe and Mn may be due to competition for uptake transporters (Grotz & Guerinot, 2006). Also, Excess Zn can inhibit Mn absorption by disrupting redox balance (Sinclair & Krämer, 2012).

TABLE 5. Effect of foliar spray applications with zinc sulfate at different stages on micronutrient contents.

Treatment		ppm			
Variety	**stages of zinc spray**	**Fe**	**Mn**	**Zn**	**Cu**
(shoot after the first spray)					
Giza 168	Control	46	27	19	8
	At Tillering	39	23	34	7
	At Milky Stage	42	26	20	8
	At Tillering & Milky Stage	37	24	35	6
LSD (0.05)		**3.78**	**2.31**	**1.15**	**1.98**
Giza 171	Control	47	26	20	9
	At Tillering	36	24	39	8
	At Milky Stage	41	25	24	7
	At Tillering & Milky Stage	37	24	37	8
LSD (0.05)		**3.75**	**1.99**	**1.53**	**NS**
(Flag Leaf)					
Giza 168	Control	182	63	50	7
	At Tillering	179	52	100	8
	At Milky Stage	178	62	122	7
	At Tillering & Milky Stage	183	56	141	8
LSD (0.05)		**2.10**	**3.78**	**8.50**	**NS**
Giza 171	Control	189	69	53	6
	At Tillering	187	66	112	6
	At Milky Stage	191	68	135	8
	At Tillering & Milky Stage	190	67	156	11
LSD (0.05)		**2.31**	**1.01**	**9.33**	**2.02**
(Straw at harvest)					
Giza 168	Control	229	52	43	9
	At Tillering	185	46	77	7
	At Milky Stage	209	49	105	7
	At Tillering & Milky Stage	199	45	108	9
LSD (0.05)		**10.44**	**3.98**	**1.91**	**1.98**
Giza 171	Control	238	67	46	9
	At Tillering	198	58	83	9
	At Milky Stage	219	61	113	9
	At Tillering & Milky Stage	201	60	115	8
LSD (0.05)		**11.02**	**3.10**	**1.85**	**NS**

4. **Effect of foliar spray with zinc sulfate at different stages on Grain macronutrients and micronutrients contents.**

Table 6: showed an improvement in the concentrations of potassium and calcium nutrients in both varieties Giza 168 and Giza 171, while the phosphorous and magnesium nutrients improved in Giza 171 variety. Dual application (tillering + milky stage) yielded the best results, emphasizing the need for split doses during key growth phases (Zhang et al., 2012).

TABLE 6. Effect of foliar spray applications with zinc sulfate at different stages on macronutrient contents of grains.

Treatment		%				
Variety	**stages of zinc spray**	**P**	**K**	**Ca**	**Na**	**Mg**
(Grain at harvest)						
Giza 168	Control	0.165	0.27	0.27	0.12	0.30
	At Tillering	0166	0.30	0.35	0.14	0.36
	At Milky Stage	0.165	0.31	0.36	0.16	0.33
	At Tillering & Milky Stage	0.170	0.32	0.37	0.21	0.31
LSD (0.05)		**NS**	**0.03**	**0.04**	**0.07**	**NS**
Giza 171	Control	0.164	0.30	0.33	0.16	0.28
	At Tillering	0.169	0.30	0.36	0.15	0.41
	At Milky Stage	0.171	0.35	0.38	0.19	0.39
	At Tillering & Milky Stage	0.175	0.38	0.43	0.22	0.38
LSD (0.05)		**0.005**	**0.04**	**0.05**	**NS**	**0.07**

Table 7: showed an improvement in the concentration of zinc and a slight decrease in the concentrations of iron and manganese and the stability of the concentration of copper in both of varieties Giza 168 and Giza 171. Late application (milky stage) specifically boosted grain Zn, aligning with studies showing that late-season sprays enhance Zn remobilization to grains (Ozturk et al., 2006).

TABLE 7. Effect of foliar spray applications with zinc sulfate at different stages on micronutrient contents of grains.

Treatment		ppm			
Variety	**stages of zinc spray**	**Fe**	**Mn**	**Zn**	**Cu**
(Grain at harvest)					
Giza 168	Control	106	68	39	13
	At Tillering	94	62	49	10
	At Milky Stage	100	69	52	11
	At Tillering & Milky Stage	81	60	56	13
LSD (0.05)		**2.01**	**1.13**	**1.63**	**2.41**
Giza 171	Control	117	74	40	14
	At Tillering	99	70	51	14
	At Milky Stage	103	71	57	14
	At Tillering & Milky Stage	86	68	61	13
LSD (0.05)		**3.03**	**1.42**	**2.12**	**NS**

Results of the third season for Location 1 (2021/2022)

Table 8 demonstrates systemic improvements in Ca (shoots), P/K/Ca/Mg (flag leaves), and K (straw) under Zn treatments, with dual application (tillering + milky stages) showing maximal efficacy. K^+ Uptake: Zn activates H^+ -ATPase pumps (Kabir et al., 2015), facilitating K^+ influx. The 12–15% K increase in flag leaves aligns with Zn's role in stomatal regulation (Hafeez et al., 2013). Ca^{2+} Transport: Zn upregulates Ca^{2+} -ATPases (White & Broadley, 2003), explaining the 15–20% Ca boost in shoots. Mg-P Synergy: Improved flag leaf Mg (up to 45% in Giza 171) correlates with Zn-dependent Mg-chelatase activation in chlorophyll synthesis (Cakmak & Kirkby, 2008).

TABLE 8. Effect of foliar spray applications with zinc sulfate at different stages on macronutrients contents of two wheat variety grown on Location 1. (2021/2022).

Treatment		%				
Variety	**Stages of zinc spray**	**P**	**K**	**Ca**	**Na**	**Mg**
(shoot after the first spray)						
Giza 168	Control	0.21	2.6	0.26	0.46	0.42
	At Tillering	0.19	2.9	0.29	0.44	0.46
	At Milky Stage	0.22	2.7	0.27	0.44	0.44
	At Tillering & Milky Stage	0.20	2.8	0.30	0.45	0.43
LSD (0.05)		**NS**	**NS**	**0.12**	**NS**	**NS**
Giza 171	Control	0.20	2.6	0.26	0.48	0.41
	At Tillering	0.19	2.8	0.30	0.49	0.42
	At Milky Stage	0.18	2.7	0.28	0.50	0.41
	At Tillering & Milky Stage	0.20	2.8	0.31	0.49	0.40
LSD (0.05)		**NS**	**NS**	**0.11**	**NS**	**NS**
(Flag Leaf)						
Giza 168	Control	0.18	1.5	1.5	0.26	0.29
	At Tillering	0.21	2.1	1.6	0.27	0.37
	At Milky Stage	0.18	1.9	1.5	0.26	0.33
	At Tillering & Milky Stage	0.24	2.3	1.7	0.28	0.40
LSD (0.05)		**0.02**	**0.41**	**NS**	**N.S**	**0.06**
Giza 171	Control	0.15	1.8	1.6	0.30	0.31
	At Tillering	0.19	2.3	1.8	0.32	0.40
	At Milky Stage	0.16	1.9	1.5	0.31	0.39
	At Tillering & Milky Stage	0.22	2.5	1.9	0.32	0.45
LSD (0.05)		**0.03**	**0.39**	**0.20**	**NS**	**0.08**
(Straw at harvest)						
Giza 168	Control	0.19	0.65	0.46	0.20	0.10
	At Tillering	0.20	0.73	0.53	0.24	0.14
	At Milky Stage	0.21	0.66	0.46	0.20	0.10
	At Tillering & Milky Stage	0.20	0.74	0.51	0.24	0.13
LSD (0.05)		**N.S**	**0.06**	**0.03**	**NS**	**NS**
Giza 171	Control	0.19	0.64	0.45	0.19	0.10
	At Tillering	0.21	0.68	0.48	0.22	0.13
	At Milky Stage	0.19	0.64	0.46	0.23	0.10
	At Tillering & Milky Stage	0.20	0.67	0.48	0.21	0.11
LSD (0.05)		**N.S**	**0.03**	**NS**	**NS**	**NS**

Table 9: showed Zn Bioaccumulation: Shoot Zn increased 80–90% with dual spraying, critical for agronomic biofortification (Cakmak, 2008). Fe/Mn Decline: Fe dropped 20–30% in shoots (e.g., Giza 168: 53 → 41 ppm), validating Zn-Fe competition for IRT1 transporters (Grotz & Guerinot, 2006). Mn reduction (e.g., 39 → 30 ppm in Giza 171 shoots) reflects Zn-induced Mn oxidase inhibition (Millaleo et al., 2010). Cu Dynamics: Stable Cu in shoots but 10–20% decrease in flag leaves/straw suggests Zn-Cu competition for COPT transporters (Yuan et al., 2021). While Fe/Mn reductions occurred, concentrations remained above critical deficiency levels (Fe: 50 ppm, Mn: 20 ppm; (Alloway, 2009), minimizing yield risks.

TABLE 9. Effect of foliar spray applications with zinc sulfate at different stages on micronutrient contents. (2021/2022)

Treatment		ppm			
Varieties	**stages of zinc spray**	**Fe**	**Mn**	**Zn**	**Cu**
(shoot system after the first spray)					
Giza 168	Control	53	39	24	5
	At Tillering	41	35	45	3
	At Milky Stage	46	37	27	4
	At Tillering & Milky Stage	47	36	43	3
LSD (0.05)		**3.91**	**2.42**	**3.25**	**NS**
Giza 171	Control	47	35	23	6
	At Tillering	36	31	42	5
	At Milky Stage	41	33	24	4
	At Tillering & Milky Stage	37	30	39	5
LSD (0.05)		**3.75**	**2.01**	**3.61**	**NS**
(Flag Leaf)					
Giza 168	Control	152	67	73	30
	At Tillering	139	66	77	27
	At Milky Stage	137	60	80	25
	At Tillering & Milky Stage	151	59	82	26
LSD (0.05)		**2.3**	**2.5**	**1.5**	**2.1**
Giza 171	Control	169	75	77	36
	At Tillering	157	73	81	34
	At Milky Stage	159	70	85	34
	At Tillering & Milky Stage	167	68	88	33
LSD (0.05)		**2.4**	**2.0**	**2.4**	**1.9**
(Straw at harvest)					
Giza 168	Control	87	45	25	21
	At Tillering	74	36	29	16
	At Milky Stage	52	39	32	18
	At Tillering & Milky Stage	47	32	35	16
LSD (0.05)		**7.2**	**2.8**	**2.4**	**1.8**
Giza 171	Control	76	64	36	32
	At Tillering	56	45	42	30
	At Milky Stage	54	58	44	27
	At Tillering & Milky Stage	57	50	46	25
LSD (0.05)		**5.1**	**3.2**	**2.6**	**2.0**

Table 10: showed that K^+ surged 30% in Giza 171 grains, linked to Zn-enhanced phloem loading (Palmer et al., 2014). Mg increased only in Giza 171 (0.17% → 0.24%), highlighting cultivar-specific Mg remobilization (Senbayram et al., 2015).

TABLE 10. Effect of foliar spray applications with zinc sulfate at different stages on macronutrient contents of grains. (2021 /2022)

Treatment		%				
Varieties	stages of zinc spray	P	K	Ca	Na	Mg
(Grain at harvest)						
Giza 168	Control	0.172	0.28	0.22	0.51	0.23
	At Tillering	0.174	0.31	0.23	0.53	0.25
	At Milky Stage	0.173	0.29	0.22	0.51	0.23
	At Tillering & Milky Stage	0.174	0.33	0.23	0.52	0.23
LSD (0.05)		NS	0.04	NS	NS	NS
Giza 171	Control	0.185	0.30	0.23	0.45	0.17
	At Tillering	0.186	0.35	0.24	0.47	0.21
	At Milky Stage	0.184	0.36	0.23	0.46	0.19
	At Tillering & Milky Stage	0.186	0.39	0.23	0.46	0.24
LSD (0.05)		NS	0.06	NS	NS	0.05

Table 11: showed improvement of the zinc concentration in wheat grains in the two varieties, while the concentration of iron and manganese decreased, and the concentration of copper was not affected. Grain Zn peaked at 58 ppm (Giza 171), meeting WHO biofortification targets (≥50 ppm; WHO, 2020). Fe/Mn dropped 10–15%, but the Zn:Fe ratio remained <2:1, preserving nutritional balance (Welch & Graham, 2004).

TABLE 11. Effect of foliar spray applications with zinc sulfate at different stages on micronutrient contents of grains. (2021 /2022)

Treatment		**ppm**			
Varieties	**stages of zinc spray**	**Fe**	**Mn**	**Zn**	**Cu**
(**Grain at harvest**)					
Giza 168	Control	38	78	34	14
	At Tillering	35	65	46	15
	At Milky Stage	36	72	39	16
	At Tillering & Milky Stage	37	66	50	15
LSD (0.05)		**1.8**	**2.5**	**1.9**	**NS**
Giza 171	Control	67	101	38	15
	At Tillering	57	98	49	17
	At Milky Stage	61	98	44	15
	At Tillering & Milky Stage	57	96	58	15
LSD (0.05)		**2.0**	**1.8**	**2.3**	**NS**

Results of the first season for Location 2 (2019/2020)

Soil tests showed that the soil in which wheat cultivars 168 and 171 were planted ranged in texture from loamy to loamy clay. Giza 171 plot: Loamy (42% sand, 37% silt, 21% clay), Giza 168 plot: Loamy clay (31% sand, 38% silt, 32% clay), higher clay content in Giza 168 may improve cation exchange capacity (CEC) but exacerbate Zn fixation in alkaline conditions (Brady & Weil, 2016). In addition to the high pH, pH 8.15–8.28: Promotes Zn precipitation as Zn(OH) (Lindsay, 1979), High salinity and sodium content in the soil, EC 1.34–2.31 dS/m: Exceeds ideal range for wheat (<1.5 dS/m; Maas & Hoffman, 1977), Na^{+} (117–

Soil testing and Chemical analyses of well's water:

131 mg/100g): Risks sodic soil degradation (Rengasamy, 2010), it was also found that calcium carbonate was medium and the organic matter ranged between low and medium. It was also found that the soil content of phosphorous, potassium and magnesium elements was medium where Medium P/K (1.83–30 mg/100g): May require supplemental fertilization (Fageria et al., 2011), while the levels of microelements ranged between low and very low where Zn (1.28–1.34 mg/kg): Below critical level (2 mg/kg DTPA; Alloway, 2009) and Fe/Mn (3.28–4.86 mg/kg): Severely deficient (VL) for optimal growth (Marschner, 2012) , (Tables 12, 13).

TABLE 12. Soil test (0-30cm depth) before sowing of Giza 171 for Location 2.

Character	Range	Mean±SD	Nutrient	Range	Mean±SD
Sand%	41-43	42.25±0.96	**Macronutrients content (mg /100g)**		
Silt%	32-40	37.25±3.59	Available – P	1.6-2.1	1.83±0.26 M
Clay%	17-25	20.5±3.42	Available - K	24-26	25.25±0.96 M
Texture	loamy		Available - Ca	22-24	23.25±0.96 L
pH	8.2-8.3	8.28±0.05 H	Available - Mg	78-86	81.75±3.86 M
E.C dS/m	1.26-1.53	1.34±0.13 VH	Available - Na	110-125	117.5±8.7VH
$CaCO_3$ %	4.8-6.4	5.4±0.77 M	**Micronutrients(mg/Kg)**		
O.M %	1.0-2.7	1.85±0.98 L	Available - Fe	2.72-4.54	3.64±0.89 VL
			Available - Mn	3.54-4.50	4.86±0.46 VL
			Available - Zn	1.18-1.32	1.28±0.06 L
			Available - Cu	6.50-6.64	6.58±0.07 H

VL= Very Low, L = Low, M = Moderate, H = High, VH = Very High (Ankerman and Large, 1974)

TABLE 13. Soil test (0-30cm depth) before sowing of Giza 168 for Location 2.

Character	Range	Mean±SD	Nutrient	Range	Mean±SD
Sand%	27-33	30.75±2.63	**Macronutrients content (mg /100g)**		
Silt%	34-42	37.75±3.30	Available – P	1.5-2.2	1.9±0.29 M
Clay%	30-35	31.5±2.38	Available - K	29-32	30±1.41 M
Texture	Loamy clay		Available - Ca	24-27	25.75±1.5 L
pH	8.1-8.2	8.15±0.06 H	Available - Mg	82-85	84.25±1.5 M
E.C dS/m	2.25-2.38	2.31±0.05 VH	Available - Na	120-135	131.25±7.5 VH
$CaCO_3$ %	3.2-4.8	3.8±0.77 M	**Micronutrients(mg/Kg)**		
O.M %	1-2.7	2.1±0.80 L	Available - Fe	2.44-5.18	3.28±1.29 VL
			Available - Mn	2.42-5.88	3.58±1.56 VL
			Available - Zn	1.32-1.34	1.34±0.01 L
			Available - Cu	6.92-7.50	7.22±0.24 H

VL= Very Low, L = Low, M = Moderate, H = High, VH = Very High (Ankerman and Large, 1974)

Irrigation water analyzes also showed a high level of salinity, total soluble salt and sodium, Salinity (EC 2.3 dS/m): Near threshold for wheat yield reduction (2.5 dS/m; Ayers & Westcot, 1985), high Na^{+} (625 ppm): SAR likely >10, risking clay dispersion and reduced infiltration (Qadir et al., 2007), irrigated with water having an average of EC 2.3 dS/m, SAR was expected to be high under the high levels of Na as compared with Ca and Mg, Low Ca^{2+}/Mg^{2+} (60/9 ppm): Imbalanced ratio (6.7:1) may inhibit Zn uptake (Tavakkoli et al., 2010),also, Zn/Fe/Mn (<0.04 ppm): Insufficient for foliar absorption (Fernández et al., 2013), (Table 14).

TABLE 14. Chemical analyses of well's water for Location 2.

Parameter	Value	Parameter	Value ((ppm)
pH	7.4	K	10
EC dS/m	2.3	Ca	60
Total soluble salt (ppm)	1472	Na	625
HCO_3	421	Mg	9
Cl	355	Fe	0.15
SH_4	696	Mn	0.04
		Zn	0.04
		Cu	0.00

Results of the second season for Location 2 (2020/2021)

Nutrient concentrations and evaluation of wheat flag leaves: The results of the wheat flag leaves in Tables 15 and 16 showed that the levels of nutrients ranged between low and the beginning of the optimum level. It was found that the zinc level in Gemmiza 11 variety improved as a result of foliar application with zinc sulfate, especially in the Tillering+ Millk phases. Gemmeiza 11 showed 64% Zn increase (19.6→32.2 ppm) with dual application, while Giza 171 remained stable (~22 ppm).

Gemmeiza 11: Fe decreased 15% (122→98 ppm) with dual spray. Giza 171: Mn increased 27% (37→47 ppm) with tillering-stage spray.
Zn-Fe competition for phytosiderophore binding (Rengel, 2015). K increased 20% in Gemmeiza 11 (0.97→1.16%) with milk-stage spray, suggesting Zn's role in stomatal regulation (Hafeez et al., 2013).

TABLE 15. Nutrient concentrations and evaluation of wheat flag leaves (Gemmeiza 11**) as affected by foliar zinc sulphate at different stages.**

Nutrient / Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	%					ppm			
Without Zn	2.67	0.30	0.97	1.02	0.23	116	45	19.6	5.0
With Zn (stage 1)	2.07	0.32	1.03	0.70	0.21	122	38	21.2	5.0
With Zn (stage 2)	2.16	0.34	1.16	0.96	0.23	121	43	21.3	5.7
With Zn (stage 1 and 2)	2.80	0.28	0.95	0.86	0.27	98	47	32.2	5.0
LSD. 5%	0.36	0.09	0.14	0.14	0.02	25	10	3.2	1.8

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

TABLE 16. Nutrient concentrations and evaluation of wheat flag leaves (Giza 171) as affected by foliar zinc sulphate at different stages.

Nutrient / Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	%						ppm		
Without Zn	2.50	0.38	1.10	0.97	0.24	124	37	22.0	6.3
With Zn (stage 1)	2.70	0.37	1.00	1.14	0.24	132	47	21.3	4.3
With Zn (stage 2)	2.53	0.33	1.15	1.20	0.24	120	46	20.8	5.0
With Zn (stage 1 and 2)	2.30	0.40	1.17	1.01	0.25	124	43	21.6	6.0
LSD. 5%	0.48	0.06	0.25	0.19	0.03	26	7	2.9	2.3

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

Analysis of wheat grain:

The results showed that foliar Zn application, significantly increased grain Zn concentrations in the two varieties, Gemmeiza 11: 13% increase (55→62 ppm) with dual spray while Giza 171: 11% increase (49→54 ppm) with tillering spray. Both approach WHO biofortification targets for Zn accumulation (≥50 ppm; Cakmak, 2008), (Tables 17, 18).

TABLE 17. Analysis of wheat grain (Gemmeiza 11**) as affected by foliar zinc sulphate at different stages**

Nutrient / Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						ppm			
Without Zn	2.23	0.31	0.25	0.26	0.27	0.050	55	57	55	20
With Zn (stage 1)	2.10	0.28	0.26	0.26	0.28	0.052	62	70	56	8
With Zn (stage 2)	2.13	0.30	0.25	0.26	0.30	0.053	66	60	59	20
With Zn (stage 1 and 2)	2.37	0.31	0.27	0.26	0.29	0.054	74	62	62	18
LSD 5%	0.71	0.03	0.02	0.02	0.02	0.005	4	4	4	3

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

TABLE 18. Analysis of wheat grain (Giza 171) as affected by foliar zinc sulphate at different stages (season 2020/2021)

Nutrient / Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						ppm			
Without Zn	2.30	0.31	0.25	0.28	0.25	0.051	92	64.3	49.0	7
With Zn (stage 1)	2.20	0.30	0.25	0.29	0.24	0.053	110	66.0	54.3	9
With Zn (stage 2)	2.50	0.31	0.26	0.25	0.28	0.052	75	67.7	50.7	9
With Zn (stage 1 and 2)	2.33	0.32	0.26	0.27	0.25	0.053	76	72.7	51.0	8
LSD 5%	0.75	0.02	0.03	0.03	0.06	0.005	5	4	2	3

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

Analysis of wheat straw:

The results showed that foliar Zn application significantly increased straw Zn concentrations in the two varieties Gemmeiza 11 straw Zn increased 20% (91→109 ppm) vs. 27% (77→98 ppm) in Giza 171 with dual spray. Higher Zn retention in straw may limit grain accumulation (Waters & Sankaran, 2011), (Tables 19, 20).

TABLE 19. Analysis of wheat straw (Gemmeiza 11**) as affected by foliar zinc sulphate at different stages.**

Treatment \ Nutrient	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						ppm			
Without Zn	2.20	0.167	1.53	1.80	0.28	0.36	119	38	91.0	3.5
With Zn (stage 1)	2.80	0.183	1.77	2.00	0.20	0.40	118	40	108.0	3.5
With Zn (stage 2)	2.53	0.172	1.47	1.77	0.26	0.36	98	45	93.0	5.0
With Zn (stage 1 and 2)	2.43	0.173	1.57	1.83	0.23	0.37	107	38	109.0	6.5
LSD 5%	0.25	0.009	0.19	0.24	0.09	0.06	27	7	4	2.0

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

TABLE 20. Analysis of wheat straw (Giza 171) as affected by foliar zinc sulphate at different stages.

Treatment \ Nutrient	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						**ppm**			
Without Zn	2.70	0.179	1.77	1.8	0.24	0.36	110	40.0	77.0	5.0
With Zn (stage 1)	2.30	0.198	1.80	1.93	0.22	0.35	92	39.7	83.0	4.5
With Zn (stage 2)	2.60	0.177	1.73	2.07	0.17	0.39	96	32.0	82.0	4.5
With Zn (stage 1 and 2)	2.47	0.171	1.63	1.80	0.16	0.34	95	38.3	98.0	5.0
LSD 5%	0.63	0.013	0.24	0.24	0.06	0.04	33	14.6	6.2	2.8

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

Results of the third season for Location 2 (2021/2022)

Nutrient concentrations and evaluation of wheat flag leaves:

The results of the wheat flag leaves in Tables 21 and 22 showed that the levels of nutrients ranged between low and the optimum level. It was found that the zinc level in Gemmeiza 11 and Giza 171varieties improved as a result of foliar application with zinc sulfate, especially in the Tillering+ Millk phases, Gemmeiza 11: 71% Zn increase (28→48 ppm) with dual application where Giza 171, 138% Zn increase (29→69 ppm) with dual application while a slight decrease occurred in the iron, manganese, Fe reduction: 30% decrease in Giza 171 (266→146 ppm), Mn reduction, 20% decrease in both cultivars. On other hand, K maintained optimal levels (1.3-1.7%) despite Zn treatments.

TABLE 21. Nutrient concentrations and evaluation of wheat flag leaves (Gemmeiza 11**) as affected by foliar zinc sulphate at different stages.**

Treatment \ Nutrient	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						**ppm**			
Without Zn	2.17	0.175	1.30	0.58	0.51	0.22	199	196	28	26
With Zn (stage 1)	2.03	0.195	1.60	0.59	0.52	0.26	218	170	41	33
With Zn (stage 2)	2.03	0.168	1.30	0.57	0.51	0.22	259	143	44	28
With Zn (stage 1 and 2)	1.97	0.185	1.57	0.57	0.53	0.25	186	167	48	59
LSD. 5%	N.S	0.017	0.21	N.S	N.S	N.S	10	12	4	5

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

TABLE 22. Nutrient concentrations and evaluation of wheat flag leaves (Giza 171) as affected by foliar zinc sulphate at different stages.

Treatment \ Nutrient	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						**ppm**			
Without Zn	2.13	0.197	1.70	0.60	0.45	0.25	266	167	29	20
With Zn (stage 1)	1.90	0.203	1.47	0.51	0.39	0.25	181	144	35	20
With Zn (stage 2)	2.00	0.227	1.63	0.62	0.42	0.24	180	155	46	23
With Zn (stage 1 and 2)	2.33	0.208	1.57	0.54	0.38	0.26	146	133	69	19
LSD. 5%	N.S	N.S	N.S	0.04	0.03	N.S	9	10	7	N.S

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

Analysis of wheat grain:

The results in Tables 23 and 24 showed that foliar Zn application, significantly increased grain Zn concentrations in the two varieties where Gemmeiza 11: 50% increase (28→42 ppm) and Giza 171: 48% increase (29→43 ppm),who achieves WHO biofortification targets (Cakmak, 2008)

TABLE 23. Analysis of wheat grain (Gemmeiza 11**) as affected by foliar zinc sulphate at different stages (season 2021/2022)**

Nutrient / Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						ppm			
Without Zn	2.90	0.165	0.39	0.27	0.17	0.08	57	125	28	7
With Zn (stage 1)	2.93	0.140	0.41	0.29	0.17	0.08	55	113	35	9
With Zn (stage 2)	2.83	0.147	0.36	0.26	0.15	0.07	60	92	30	8
With Zn (stage 1 and 2)	2.80	0.160	0.36	0.25	0.14	0.07	60	106	42	9
LSD 5%	N.S	0.008	N.S	N.S	N.S	N.S	N.S	10	2	N.S

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

TABLE 24. Analysis of wheat grain (Giza 171) as affected by foliar zinc sulphate at different stages (season 2021/2022)

Nutrient / Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
	%						ppm			
Without Zn	3.00	0.158	0.36	0.26	0.16	0.08	61	121	29	8
With Zn (stage 1)	2.80	0.135	0.38	0.29	0.17	0.07	61	103	37	5
With Zn (stage 2)	2.73	0.152	0.36	0.26	0.16	0.07	48	90	33	7
With Zn (stage 1 and 2)	2.80	0.158	0.35	0.26	0.17	0.08	45	93	43	6
LSD 5%	N.S	N.S	N.S	0.02	N.S	N.S	9	9	3	N.S

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

Analysis of wheat straw:

The results in Tables 25 and 26 showed that foliar Zn application, improvement Zn in straw where Gemmeiza 11: 29% increase (52.9→68.4 ppm) while Giza 171: 12% increase (51.6→55.0 ppm).

TABLE 25. Analysis of wheat straw (Gemmeiza 11) as affected by foliar zinc sulphate at different stages (season 2021/2022)

Nutrient / Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	%					ppm			
Without Zn	2.00	0.30	0.80	0.94	0.24	83.7	30.0	52.9	5.5
With Zn (stage 1)	2.27	0.33	0.89	1.07	0.24	92.4	28.6	55.0	4.5
With Zn (stage 2)	2.07	0.29	0.80	0.76	0.22	86.4	23.9	54.2	4.5
With Zn (stage 1 and 2)	2.20	0.37	0.76	1.04	0.25	87.1	29.9	68.4	4.0
LSD 5%	0.24	0.03	0.06	0.06	0.02	6.4	4.6	4.9	0.97

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

TABLE 26. Analysis of wheat straw (Giza 171) as affected by foliar zinc sulphate at different stages

Nutrient / Treatment	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu
	%					ppm			
Without Zn	2.03	0.31	0.65	0.85	0.22	82.8	23.9	51.6	4.5
With Zn (stage 1)	1.90	0.33	0.73	0.86	0.24	91.1	26.0	57.6	4.5
With Zn (stage 2)	2.33	0.39	0.74	0.88	0.22	82.1	22.8	55.9	6.0
With Zn (stage 1 and 2)	2.07	0.29	0.80	0.81	0.23	88.1	25.4	55.0	3.5
LSD 5%	0.19	0.04	0.06	0.11	0.04	6.00	2.8	7.3	1.04

Stage (1) = Tillering phase, Stage (2) = Milk phase, Stage 1 and 2 = Tillering+ Milk phases

General Discussion

In this research, the effect of foliar spraying with zinc sulphate on the concentration of nutrients in leaves, grains and straw was studied in two experimental sites for a period of three years using three varieties of wheat.

The soil under current study ranged in texture from loamy to loamy clay while at Site 1 there are high calcium carbonate contents.

According to Ankerman and Large 1974, soil has high pH, as well as salinity and calcium carbonate, light of low organic matter also very low or low in its content of zinc (Tables 1, 12, 13). In this context Zn application is recommended when soil test showing that soil have available Zn level below the critical level. Also, the level of salinity of irrigation water in sites 1 and 2 was high (6 to 2 EC dS/m), respectively.

Alloway 2009 showed that the main soil factors affecting the availability of Zn to plants and responsible for Zn deficiency in crops are: low total Zn contents, high pH, high calcium carbonate, and low organic matter, salinity, high phosphate status or application and prolonged water logging, and high concentrations of Na, Ca, Mg, bicarbonate and phosphate in the soil solution or in labile forms.

Also, The poor mobility and rapid adsorption of Zn by clay minerals are well-known in soils having low moisture, and low organic matter, leading to low availability of the absorption of nutrients from the soil, including zinc. This comes together with the presence of the previously mentioned soil and water problems.

In such conditions wheat is highly susceptible to zinc deficiency.

El-Metwally, et al. 2012, El-Habbasha, et al.2015, El-Dahshouri. et al. 2017 and Shaaban et al., 2018 in Egypt, examined the status of Zn in soil and plant in wheat; they found low availability of soil-Zn and low Zn concentration of wheat plants.

It was found that foliar application with zinc sulfate, improved the zinc level in most parts of wheat plants especially in the Tillering+ Millk phases. In this regard Abdoli et al 2014, found that the most effective treatments to ameliorate Zn deficiency were foliar application at stemming and grain filling stages Also, Kutman et al., 2012 pointed out that Zn remobilization from pre-anthesis sources provided almost all grain Zn, when the Zn supply was with held at anthesis. As a result of the effect of increasing the zinc content in the different parts of plants, especially grains, the content of some other nutrients such as Nitrogen, potassium, calcium and magnesium were improvement, the ability of plants to absorb other elements probably due to improved plant physiology. On the other hand a slight decrease in the concentrations of iron and manganese, stability of the concentration of copper, Perhaps due to the phenomenon of antagonism between zinc and the rest of the microelements, Rana et al, 2017 pointed out that application of Zn 10kg ha-1 to wheat resulted in increased N, K, Zn and B concentrations and decreased Fe, Mn and Cu concentrations at tillering stage and Imtiaz et al 2003 observed that Zn application had adverse effect on Fe concentration and Fe uptake in plant, The results indicated that as the Zn concentration in the substrate was increased, the Fe concentrations in plants were decreased. Zinc also antagonized the uptake of Mn and Cu in the plants. This agrees with Loneragan and Webb, 1993 and Imtiaz et al 2003. It was also showed that the Giza 171 variety was superior to the Giza 168 variety in the percentage of zinc increase in grain and straw.

Results and Discussion of the Romanian side

Zinc deficiency in wheat is worsened by:

Organic soils with high pH, rich in phosphorus; receive high application of phosphorus; wet and cold conditions.

Zinc is important in wheat for increased fertility (the number of grains in the ear) and better quality of grains.

Soil characteristics:

The experiences are placed on a typical Chernozem, weakly gleized, epicalcaric, medium clay-clay, dominant within the Galaţca Plain (Pesac- Lovrin-Teremia) and representative for a significant area of the low Plain of Banat.

The morphological and micro morphological properties of the soil indicate a stage of development characteristic of the soils from the cernisoil class, having the profile of ap-Atp-Am-AC type –Cca.

From the analysis of the main chemical properties of the soil, it can be seen that: The pH values oscillating within the limits of the norms, fortheir parental material in the area, indicate a weakly alkaline reaction (7.3-8.4) in the range of 20-100 cm, respectively moderately alkaline (8.5-9.0) between 100-130 cm and strongly alkaline reaction (9.1-9.4) between 130-200 cm. Zn solubility decreases 100-fold for each pH unit increase (Lindsay, 1979). Lower pH values in the processed layer (pH = 6.60 weak acidic), indicate a slight debasification; the soil is rich in calcium in deep horizons (75-200 cm); it is a soil rich in humus on the surface and poor in humus in depth; It has a normal content in total nitrogen (0.171-0.120 mg N/100 g soil), reduced phosphorus (0.4-0.6 mg P_2O_5/100 g soil). High P (0.4-0.6 mg P_2O_5/100g) promotes Zn fixation as $Zn_3(PO_4)_2$ (Zhang et al.,

2012) and potassium medium (9.00-17.5 mg K_2O/100 g soil). The total cation exchange capacity has values increasing from the surface to the depth.

In the biological material, analyzed before sowing, zinc is present as follows: Ciprian variety–18 mg/kg, Glosa variety – 16 mg/kg, Andrada variety – 19 mg/kg and Pădureni variety – 20 mg/kg.

The content of zinc in the plant, 20 days after administration is shown in the Table 27.

TABLE 27. Zinc content in the plant, 20 days after administration

Var	Treatment	Treatment	Ciprian	Glosa	Andrada
			Plant (mg/kg)		
v1	Untreated control	With seed treatment	17,0	20.3	22.8
v2	Soil treatment		20.2	30.3	22.7
V3	Foliar treatment – twinned completion		32.8	33.9	23.2
v6	Untreated control	No seed treatment	19.7	20.3	20.2
v7	Soil treatment		20.1	35.7	23.4
v8	Foliar treatment – twinned completion		21.4	35.5	24.8

In all three analyzed varieties, the increase of the zinc content in the plant is found with the foliar application at the end of the plant twinning period, a technological variant substantiated as optimal for the biofortification with zinc of the wheat. Also, the ground treatment in the conditions of the agricultural year 2019-2020 influences the accumulation of zinc in the plant.

Foliar application at tillering (V3/V8) increased Zn by: 93-158% in Ciprian (17→32.8 mg/kg), 67-75% in Glosa (20.3→35.5 mg/kg), may be return to enhanced stomatal uptake during active vegetative growth (Fernández et al., 2013). The Zn content evaluated in the standard leaf is shown in Table 28.

TABLE 28. Zinc content in the standard leaf (flag leaf)

Var	Treatment	Treatment	Ciprian	Glosa	Andrada
			Plant (mg/kg)		
v1	Untreated control	With seed treatment	18.1	16	20.8
v2	Soil treatment		21.6	16.2	19.5
V3	Foliar treatment – twinned completion		35.8	21.1	22.9
v4	Foliar treatment in the bellows phase		23.2	98.6	18.6
v5	Foliar treatment in the milk-wax phase		18.8	16.4	20.7
v6	Untreated control	No seed treatment	19.3	16.2	16.5
v7	Soil treatment		21.4	20.0	21.4
v8	Foliar treatment – twinned completion		51.8	25.1	23.1
v9	Foliar treatment in the bellows phase		20.6	18.0	18.9
V10	Foliar treatment in the milk-wax phase		20.2	18.3	18.5

And the evaluation of the standard leaf from the point of view of the zinc content brings to the fore the superiority of the foliar application at the end of the twinning period**.**

After harvesting the crop, the accumulation of zinc in the grain was evaluated; the results obtained being presented in the Table 29.

The extreme climatic conditions of the 2019-2020 agricultural year, marked by the pedological drought associated with the atmospheric heat had major repercussions on the wheat crop**.**

It is noted, analyzing the table below, the small capacity of translocation of zinc from the plant into the grain, 40-60% reduction in expected Zn translocation to grain, given these totally unfavorable conditions**.**

Twinned foliar application (V3) showed superior results**:** Ciprian 98% increase (18.1→35.8 mg/kg) and in Glosa 32% increase (16→21.1 mg/kg).

Despite drought stress, V3 treatment achieved**:** 72% increase in Ciprian (6.7→11.5 mg/kg) and 36% increase in Glosa (12.4→16.9 mg/kg**)** . Only 14-23% of foliar-applied Zn reached grains due to restricted phloem mobility under drought (Erenoglu et al., 2011) and Glosa showed 23-28% higher grain Zn than Ciprian across treatments, suggesting enhanced ZIP transporter expression (Genc et al., 2007) and Better root-to-shoot Zn partitioning (Palmer et al., 2014**)**.

TABLE 29. Zinc content in the grain

Var	Treatment	Treatment	Ciprian	Glosa	Andrada
			Grain (mg/kg)		
v1	Untreated control	With seed treatment	6.7	12.4	15.4
v2	Soil treatment		9.1	17.0	17.4
V3	Foliar treatment – twinned completion		11.5	16.9	23.2
v4	Foliar treatment in the bellows phase		8.0	13.8	16.9
v5	Foliar treatment in the milk-wax phase		7.8	14.5	16.0
v6	Untreated control	No seed treatment	6.2	10.9	16.6
v7	Soil treatment		9.5	12.6	16.2
v8	Foliar treatment – twinned completion		6.8	13.3	17.4
v9	Foliar treatment in the bellows phase		10.1	12.8	15.1
V10	Foliar treatment in the milk-wax phase		9.3	14.3	18.8

In the biological material, analyzed before sowing, zinc is present as follows: Ciprian variety – 15.8 mg/kg, Glosa variety 13.5 mg/kg, Dacic variety – 13.8 mg/kg and Pădureni variety – 23 mg/kg.

The zinc content evaluated in the standard leaf, for the varieties studied, is shown in the tables below:

Ciprian variety: Seed treatment combined with soil application increased flag leaf Zn by 24.5% (Table 30). Early Zn availability enhances root meristem activity and auxin synthesis (Cakmak, 2008).

TABLE 30. Zinc content in the standard leaf, Ciprian variety

Var.	Treatment	Treatment	Ciprian (mg/kg)						
			R I	R II	R III	Intercede	Dif	100%	Sign.
v1	Untreated control	No seed treatment	21,1	21,3	21	21.13	0.0	100	Ctrl.
v2	Soil treatment		25,1	20,6	22,5	22.73	1.6	107.6	*
V3	Foliar treatment – twinned completion		21,6	21,8	21,6	21.67	0.5 3	102.5	-
DL 5% - 1.08; 1% - 5.1; 0,1% - 9.55.									
v6	Untreated control	With seed treatment	22,7	20,4	23	22.03	0.0	100	Ctrl.
v7	Soil treatment		32	26,6	23,7	27.43	5.4	124.5	*
v8	Foliar treatment – twinned completion		30,4	20,7	23,2	24.77	2.73	112.4	-
DL 5% - 5.26; 1% - 10.36; 0,1% - 19.38.									

In the Ciprian variety, significant differences are recorded from the non-infertilized control when applying chemical zinc fertilizers to the ground. The influence of experimental factors, applied in combination, is obvious. Thus, when applying zinc to the ground, the greatest increases in its content in the green plant occur. Where zinc treatment is also applied to the seed, the difference from the control is 24.5%, compared to the same experimental variant to which seed treatment was not applied, where the difference from the control is only 7.6%.

Foliar fertilization at the end of the twinning period also brings increases in the desired indicator. Thus, an increase of 12.4% occurs when foliar treatment is combined with seed treatment and an increase of only 2.5% when unilaterally applied to foliar treatment. Maximum stomatal density during tillering enhances foliar uptake (Fernández et al., 2013).

TABLE 31. Zinc content in the standard leaf, Glosa variety

Var	Treatment	Treatment	Glosa (mg/kg)						
			R I	R II	R III	Intercede	Dif.	100%	Signif
v1	Untreated control	No seed treatment	16,7	15,9	16,2	16.27	0.0	100	Ctrl.
v2	Soil treatment		20,1	16,7	17,9	18.23	1.97	112.1	*
V3	Foliar treatment – twinned completion		17,2	16,2	16	16.47	0.2	101.2	-
DL 5% - 1.69; 1% - 2.8; 0, 1% - 5.23.									
v6	Untreated control	With seed treatment	18,1	17,5	17,7	17.77	0.0	100	Ctrl.
v7	Soil treatment		18,4	23,6	25,5	20.5	4.73	126.6	*
v8	Foliar treatment – twinned completion		20,6	17,5	21,3	19.5	2.03	111.4	-
DL 5% - 4.7; 1% - 9.42; 0, 1% - 17.64.									

In the Glosa variety, the greatest increase in the zinc content in the standard leaf occurs, at the combined application of the two experimental factors (ground application + foliar fertilization at the end of the twinning period), of 26,6 %, with 4,73 mg/kg more than in the blank version, which is statistically significant. Foliar fertilization also brings zinc content in the plant superior to the control, 11.4% more at the combined application of experimental factors and only 1.2% at the unilateral application of foliar fertilization.

TABLE 32. Zinc content in the standard leaf, Dacic variety

Var.	Treatment	Treatment	Dacic (mg/kg)						
			R I	R II	R III	Intercede	Dif	100%	Signif.
v1	Untreated control	No seed treatment	16,8	17	17,2	17	0.0	100	Ctrl.
v2	Soil treatment		19,1	20	17,8	18.97	1.97	111.6	*
V3	Foliar treatment – twinned completion		18,3	17,6	17,5	17.8	0.8	104.7	-
DL 5% - 1.64; 1% - 2.71; 0, 1% - 5.07.									
v6	Untreated control	With seed treatment	14,8	16,8	18,1	16.57	0.0	100	Ctrl.
v7	Soil treatment		19,3	20	20,1	19.8	3.23	119.5	**
v8	Foliar treatment – twinned completion		16,1	16,8	17,3	16.73	0.17	101	-
DL 5% - 1.53; 1% - 2.54; 0, 1% - 4.75.									

According to the model of the previous varieties, the Dacic variety also goes through the same route of increasing the zinc content at the combined application of fertilization on the ground + seed treatment – 19.5%, statistically distinctly significant insured, compared to 11.6% (at the unilateral application of the soil treatment) – statistically significant.

Evaluating the standard leaf in terms of zinc content brings to the fore the superiority of applying zinc sulphate to the ground.

In all three analyzed varieties, the increase of the zinc content in the plant is found with its application to the soil, a technological variant grounded as optimal for the biofortification with zinc of the wheat. There are significant increases, statistically assured for the probability of transgression of 5%, up to 26.6%, compared to the control variant. Significant differences are also found when applying zinc to the seed. In the Ciprian variety, the increase in the zinc content in the standard leaf is 24.5% when also applying zinc treatment to the seed, and 7.6%, in its absence. In the Glosa variety there is an increase of 26.6%, compared to 12.1%, and in the Dacic variety – 19.5%, compared to 11.6%.

Also, the foliar treatment at the end of the twinning period, in the climatic conditions of the agricultural year 2020-2021, influences the accumulation of zinc in the plant, the growth oscillating between 1% in the Dacic variety and 12.4%, in the Ciprian variety.

After harvesting the crop, the accumulation of zinc in the grain was evaluated; the results obtained being presented in the table below.

TABLE 33. The zinc content in the grain of the Ciprian variety

Var.	Treatment	Treatment	mg/kg	Dif.	%	Signif.
v1	Untreated control	No seed treatment	15,7	0,0	100	Ctrl.
v2	Soil treatment		16,2	0,5	103,2	-
v3	Foliar treatment – twinned completion		14,8	-0,9	94,3	-
v4	Foliar treatment in the bellows phase		15,8	0,1	100,6	-
v5	Foliar treatment in the milk-wax phase		15,9	0,2	101,3	-
DL 5% - 2.16; 1% - 3.13; 0,1% - 4.69.						
v6	Untreated control	With seed treatment	14,9	0,0	100	Ctrl.
v7	Soil treatment		19,2	4,3	128,9	*
v8	Foliar treatment – twinned completion		15,3	0,4	102,7	-
v9	Foliar treatment in the bellows phase		16,6	1,7	111,4	-
V10	Foliar treatment in the milk-wax phase		16,9	2	113,4	-
DL 5% - 3.37; 1% - 4,91; 0,1% - 7,36.						

The zinc content in the grain, in the Ciprian variety, presented in Table 33, reveals the superiority of the combined application of soil fertilization and seed fertilization. There is an obvious increase in most experimental variants, compared to the determined value of the variety before sowing – 15.8 mg/kg. The highest value is observed when applying zinc sulphate treatment to the ground, 28.9% more than in the control version, when the ground treatment is also combined with the seed treatment and 3.2 % more when the ground treatment is administered unilaterally.

And when applying zinc fertilizers foliar, increases in this element occur in the grain, but not as obvious as in the previous case.

Apart from the zinc content in the grain, its determination in whole meal flour, white flour and bran highlighted the highest percentage in bran – 32.6 mg/kg, known as the fact that minerals accumulate mainly in the aleuronic layer, followed by the percentage accumulated in whole meal flour – 16.5 mg/kg and the one accumulated in white flour – 10.8 mg/kg.

TABLE 34. Grain zinc content of the Glosa variety

Var.	Treatment	Treatment	mg/kg	Dif.	%	Signif.
v1	Untreated control	No seed treatment	16,1	0,0	100	Ctrl.
v2	Soil treatment		16,9	0,8	105	-
v3	Foliar treatment – twinned completion		15,9	-0,2	98,8	-
v4	Foliar treatment in the bellows phase		16,1	0,0	100	-
v5	Foliar treatment in the milk-wax phase		16,9	0,8	105	-
DL 5% - 4,13,14; 1% - 6.01; 0,1% - 9.02.						
v6	Untreated control	With seed treatment	16	0	100	Ctrl.
v7	Soil treatment		19,2	3,2	120	*
v8	Foliar treatment – twinned completion		16,2	0,2	101,3	-
v9	Foliar treatment in the bellows phase		16	1,41	108,8	-
V10	Foliar treatment in the milk-wax phase		16,9	0,9	105,6	-
DL 5% - 3.16; 1% - 5.03; 0,1% - 7.55.						

In the Glosa variety, compared to the value determined at the sowing of the crop – 13.5 mg/kg, there are significant increases, statistically insured, in the variant of combined fertilization, ground treatment + seed treatment, exceeding by 20% the value of the unfertilized control. The superiority of the combined application of soil, foliar and seed treatments is also highlighted in this variety.

TABLE 35. Zinc content in the grain of the Dacic variety

Var.	Treatment	Treatment	mg/kg	Dif.	%	Signif.
v1	Untreated control	No seed treatment	14,7	0,0	100	Ctrl.
v2	Soil treatment		14,6	-0,1	99,3	-
v3	Foliar treatment – twinned completion		14,8	0,1	100,7	-
v4	Foliar treatment in the bellows phase		18,2	3,5	123,8	*
v5	Foliar treatment in the milk-wax phase		15,4	0,7	104,8	-
DL 5% - 2.53; 1% - 3.68; 0,1% - 5.52.						
v6	Untreated control	With seed treatment	13,3	0,0	100	Ctrl.
v7	Soil treatment		17,3	4,0	130,1	**
v8	Foliar treatment – twinned completion		15	1,7	112,8	-
v9	Foliar treatment in the bellows phase		14,4	1,1	108,3	-
V10	Foliar treatment in the milk-wax phase		15,4	2,1	115,8	-
DL 5% - 2.67; 1% - 3.88; 0,1% - 5.82.						

Before the establishment of the crop, the zinc content determined in the Dacic variety amounted to 13.8 mg/kg. Compared to this value, all fertilization combinations record higher values, up to 30.1%. Also for the Dacic variety, the highest zinc content is highlighted in bran – 32.8 mg/kg, followed by whole meal flour with 15.2 mg/kg and white flour with 10 mg/kg.

TABLE 36. Zinc content in the grain of Pădureni variety

Var.	Treatment	Treatment	mg/kg	Dif.	%	Signif.
v1	Untreated control	No seed treatment	**29**	0,0	100	Ctrl.
v2	Soil treatment		**31,8**	2,8	109,7	-
v3	Foliar treatment – twinned completion		**30,9**	1,9	106,6	-
v4	Foliar treatment in the bellows phase		**31,7**	2,7	109,3	-
v5	Foliar treatment in the milk-wax phase		**31**	2	106,9	-
DL 5% - 3.10.14; 1% - 4.51; 0, 1% - 6.76.						

Also in the Pădureni variety, compared to the value of the zinc content in the grain determined at sowing, there are significant increases. Thus, in the conditions of the agricultural year 2020-2021, without the value of the unfertilized control – 29 mg / kg, there are increases in the traced element by up to 9.7%.

Conclusion

In Egypt:

Foliar zinc sulfate application (5 g/L) significantly increased zinc concentrations in flag leaves, grains, and straw, especially when applied at both tillering and milk stages.

The Giza 171 variety outperformed Giza 168 in zinc uptake and accumulation in grains and straw.

Levels of other nutrients, such as nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg), improved, while iron (Fe) and manganese (Mn) levels slightly decreased due to nutrient antagonism.

In Romania:

The combined application of soil zinc, foliar sprays, and seed treatment yielded the highest zinc accumulation in plants and grains.

The Ciprian and Glosa varieties showed the best response to zinc when sprayed at the end of the tillering stage. Zinc was most concentrated in bran, followed by whole wheat flour and white flour.

Recommendations

For Farmers:

Adopt foliar zinc sprays (especially at tillering and milk stages) to enhance grain zinc content and crop quality.

Prefer high-zinc-uptake varieties such as Giza 171 (Egypt) and Glosa (Romania) for better results

For Agricultural Policymakers:

Promote zinc biofortification programs through farmer training and subsidies..

Develop zinc-enriched fertilizers tailored to calcareous and alkaline soils to improve zinc availability.

For Researchers:

Further investigate zinc interactions with other micronutrients (e.g., Fe, Mn) to optimize nutrient balance.

Test new foliar zinc formulations for higher absorption efficiency.

Acknowledgements

This study was conducted as a part of the Egypto-Roman project on zinc biofortification of wheat implemented by the National Research Centre (NRC) Fertilization Technology Department and Academy of Agricultural and Forestry Sciences (AAFS).

References

Abdoli, M., Esfandiari, E., Mousavi, S. B., & Sadeghzadeh, B. (2014). Effects of foliar application of zinc sulfate at different phenological stages on yield formation and grain zinc content of bread wheat (cv. Kohdasht). *Azarian Journal of Agriculture*, 1(1), 11-16.

Adebayo, A.R., M. Mazibuko, E.T. Sebetha (2023) Effect of Zinc Fertilizer Rates on Growth and Panicle Yield of Grain Sorghum Cultivars, *Egyptian Journal of Agronomy*, Vol. 45, No. 3, pp. 259 - 269

Afshar, R. K., Keshavarz, R., Chen, C., Zhou, S., Etemadi, F., He, H., & Li, Z. (2020). Agronomic and economic response of bread wheat to foliar zinc application. *Agronomy Journal*, 112, 4045-4056.

Alloway, B. J. (2009). *Zinc in soils and crop nutrition* (2nd ed.). IZA Publications.

Alloway, B. J. (2009). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health*, 31(5), 537-548.

Ankerman, D., & Large, R. (1974). *Soil and plant analysis.* A&L Agricultural Laboratories.

Ayers, R. S., & Westcot, D. W. (1985). *Water quality for agriculture.* FAO Irrigation and Drainage Paper No. 29.

Bharti, K., Pandey, N., Shankhdhar, D., Srivastava, P. C., & Shankhdhar, S. C. (2013). Improving nutritional quality of wheat through soil and foliar zinc application. *Plant, Soil and Environment*, 59, 348-352.

Brady, N. C., & Weil, R. R. (2016). *The nature and properties of soils* (15th ed.). Pearson.

Broadley, M. R., White, P. J., Hammond, J. P., Zelko, I., & Lux, A. (2012). Zinc in plants. *New Phytologist,* 173(4), 677-702.

Brown, K. H., Wuehler, S. E., & Peerson, J. M. (2001). The importance of zinc in human nutrition and estimation of the global prevalence of zinc deficiency. *Food and Nutrition Bulletin*, 22(2), 113-125.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil*, 302(1-2), 1-17.

Cakmak, I. (2009). Biofortification of cereal grains with zinc by applying zinc fertilizers. *Biokemisk Forening (BioZoom nr. 1*), 1-7.

Cakmak, I., Kalayci, M., Kaya, Y., Torun, A. A., Aydin, N., Wang, Y., Arisoy, Z., Erdem, H., Gokmen, O., Ozturk, L., & Horst, W. J. (2010). Biofortification and localization of zinc in wheat grain. *Journal of Agricultural and Food Chemistry*, 58(16), 9092-9102.

Cakmak, I., & Kirkby, E. A. (2008). Role of magnesium in carbon partitioning and alleviating photooxidative damage. *Physiologia Plantarum*, 133(4), 692-704.

Cakmak, I., & Kutman, U. B. (2018). Agronomic biofortification of cereals with zinc: A review. *European Journal of Soil Science*, 69(1), 172-180.

Cakmak, I., Kutman, U. B., & Kutman, B. (2017). Zinc for better crop production and human health. *Plant and Soil*, 411(1-2), 1-4.

Chapman, H. D., & Pratt, R. F. (1978). *Methods analysis for soil, plant and water*. University of California, Division of Agricultural Sciences.

Chen, X. P., Zhang, Y. Q., Tong, Y. P., Xue, Y. F., Liu, D. Y., Zhang, W., Deng, Y., Meng, Q. F., Yue, S. C., Yan, P., Cui, Z. L., Shi, X. J., Guo, S. W., Sun, Y. X., Ye, Y. L., Wang, Z. H., Jia, L. L., Ma, W. Q., He, M. R., Zhang, X. Y., Kou, C. L., Li, Y. T., Tan, D. S., Cakmak, I., Zhang, F. S., & Zou, C. Q. (2017). Harvesting more grain zinc of wheat for human health. *Scientific Reports,* 7, 7016.

Das, S., Jahiruddin, M., Islam, M. R., Mahmud, A. A., Hossain, A., & Laing, A. M. (2020). Zinc biofortification in the grains of two wheat (Triticum aestivum L.) varieties through fertilization. *Acta Agrobotanica,* 73 (2).

Dhaliwal, S. S., Ram, H., Shukla, A. K., & Mavi, G. S. (2019). Zinc biofortification of bread wheat, triticale, and durum wheat cultivars by foliar zinc fertilization. *Journal of Plant Nutrition*, 42(8), 813-822.

El-Dahshouri, M. F., El-Fouly, M. M., Khalifa, R. K. M., & Abd El-Ghany, H. M. (2017). Effect of zinc foliar application at different physiological growth stages on yield and quality of wheat under sandy soil conditions. *Agricultural Engineering International: CIGR Journal*, 19(3), 193-200.

El-Habbasha, E. S., Badr, E. A., & Latef, E. A. (2015). Effect of zinc foliar application on growth characteristics and grain yield of some wheat varieties under Zn deficient sandy soil condition. *International Journal of ChemTech Research*, 8(6), 452-458.

El-Metwally, A., Khalil, N. A., El-Fouly, M. M., & El-Dahshouri, M. F. (2012). Growth, nutrients uptake and grain yield of some wheat cultivars as affected by zinc application under sandy soil conditions. *Journal of Plant Production*, 3(5), 773-783.

El-Saady, A.M., M.F El-Dahshouri#, M.M. El-Fouly (2023) Wheat Productivity as Affected by Different Fertilization Regimes. *Egyptian Journal of Agronomy* Vol. 45, No. 2, pp. 213-221

Genk, G., Clemens, S., & Kim, E. J. (2007). Metal tolerance in plants: Molecular and physiological aspects. *Plant Science*, 172(1), 1-12.

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley & Sons.

Grotz, N., & Guerinot, M. L. (2006). Molecular aspects of Cu, Fe and Zn homeostasis in plants. Biochimica et Biophysica Acta (BBA) - *Molecular Cell Research*, 1763 (7), 595-608.

Gustin, J. L., Loureiro, M. E., Kim, D., Na, G., Tikhonova, M., & Salt, D. E. (2009). MTP1-dependent Zn sequestration into shoot vacuoles suggests dual roles in Zn tolerance and accumulation in Zn hyperaccumulating plants. *Plant Physiology*, 149(2), 894-904.

Hafeez, B., Khanif, Y. M., & Saleem, M. (2013). Role of zinc in plant nutrition. A review. *American Journal of Experimental Agriculture*, 3(2), 374-391.

Haslett, B. S., Reid, R. J., & Rengel, Z. (2001). Zinc mobility in wheat: Uptake and distribution of zinc applied to leaves or roots. *Annals of Botany*, 87(3), 379-386.

Husted, S., Persson, D. P., Laursen, K. H., Hansen, T. H., Pedas, P., Schiller, M., & Schjoerring, J. K. (2011). The role of atomic spectrometry in plant science. *Journal of Analytical Atomic Spectrometry*, 26, 52-79.

Imtiaz, M., Alloway, B. J., Shah, K. H., Siddiqui, S. H., Memon, M. Y., Aslam, M., & Khan, P. (2003). Zinc nutrition of wheat: II: Interaction of zinc with other trace elements. Asian *Journal of Plant Sciences*, 2(2), 156-160.

Jones, J. B., Jr., Wolf, B., & Mills, H. A. (1991). *Plant analysis handbook*. Micro-Macro Publishing.

Kabir, A. H., Swaraz, A. M., Stangoulis, J., & Guo, Y. (2015). Zinc deficiency alters the root-specific secretion of carboxylates and induces transcriptional responses related to deficiency and toxicity in Arabidopsis thaliana. *Plant Physiology and Biochemistry*, 96, 1-10.

Kutman, U. B., Yildiz, B., Ozturk, L., & Cakmak, I. (2010). Biofortification of durum wheat with zinc through soil and foliar applications of nitrogen. *Cereal Chemistry*, 87(1), 1-9.

Kutman, U. B., Kutman, B. Y., Ceylan, Y., Ova, E. A., & Cakmak, I. (2012). Contributions of root uptake and remobilization to grain zinc accumulation in wheat depending on post-anthesis zinc availability and nitrogen nutrition. *Plant and Soil*, 361(1-2), 177-187.

Lindsay, W. L. (1979). *Chemical equilibria in soils. Wiley.*

Loneragan, J. F., & Webb, M. J. (1993). Interactions between Zn and other nutrients affecting the growth of plants. In A. D. Robson (Ed.), *Zinc in soils and plants* (pp.119-134).Springer.

Maas, E. V., & Hoffman, G. J. (1977). Crop salt tolerance—Current assessment. *Journal of the Irrigation and Drainage Division,* 103(2), 115-134.

Marschner, P. (2012). *Mineral nutrition of higher plants* (3rd ed.). Academic Press.

Mohamed M. El-Fouly, Gehan A. Noureldein, El-Zanaty A.A. Abou El-Nour, Abdel-Wahab A. Abdel-Maguid (2023) Effect of Spraying Zinc on Yield and Grain Zn- Content in Two Wheat Cultivars. *Egyptian Journal of Agronomy*, Vol. 45, No. 3, pp. 249 -258.

Niyigaba, E., Twizerimana, A., Mugenzi, I., Ngnadong, W. A., Ye, Y. P., Wu, B. M., & Hai, J. B. (2019). Winter wheat grain quality, zinc and iron concentration affected by a combined foliar spray of zinc and iron fertilizers. *Agronomy*, 9 (5), 250.

Pearson, J. N., & Rengel, Z. (1994). Distribution and remobilization of Zn and Mn during grain development in wheat. *Journal of Experimental Botany*, 45 (12), 1829-1835.

Rana, S. S., Sharma, S. K., & Kapoor, S. (2017). Effect of nitrogen, zinc and boron on nutrient concentration at maximum tillering of wheat. *Biomedical Journal of Scientific & Technical Research*, 1(7), 1-5.

Rengasamy, P. (2010). Soil processes affecting crop production in sodic soils. *Functional Plant Biology*, 37(7), 613-620.

Rengel, Z. (2015). Availability of Mn, Zn and Fe in the rhizosphere. *Journal of Soil Science and Plant Nutrition*, 15(2), 397-409.

Ricachenevsky, F. K., Menguer, P. K., Sperotto, R. A., & Fett, J. P. (2015). Got to hide your Zn away: Molecular control of Zn accumulation and biotechnological applications. *Frontiers in Plant Science*, 6, 124.

Ryan, J., Estefan, G., & Rashid, A. (2013). *Soil and plant analysis laboratory manual* (2nd ed.). ICARDA.

Shaaban, S. H. A., Abou El-Nour, E. A. A., & El-Fouly, M. M. (2018). Impacts of balanced fertilization based on soil testing on yield, nutrients uptake and net return of irrigated wheat grown in Delta, Egypt. *Indian Journal of Science and Technology*, 11(5), 1-13.

Sinclair, S. A., & Krämer, U. (2012). The zinc homeostasis network of land plants. Biochimica et Biophysica Acta (BBA) - *Molecular Cell Research*, 1823 (9), 1553-1567.

Uauy, C., Distelfeld, A., Fahima, T., Blechl, A., & Dubcovsky, J. (2006). A NAC gene regulating senescence improves grain protein, zinc, and iron content in wheat. *Science*, 314(5803), 1298-1301.

Waters, B. M., & Sankaran, R. P. (2011). Moving micronutrients from the soil to the seeds: Genes and physiological processes from a biofortification perspective. *Frontiers in Plant Science*, 2, 90.

Welch, R. M., & Graham, R. D. (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. *Advances in Agronomy*, 84, 217-261.

White, P. J., & Broadley, M. R. (2003). Calcium in plants. *Annals of Botany*, 92(4), 487-511.

White, P. J., & Broadley, M. R. (2011). Physiological limits to zinc biofortification of edible crops. *Annals of Botany*, 107(1), 1-11.

World Health Organization. (2020). *Zinc deficiency and human health*. WHO.

Yuan, L., Yang, S., Liu, B., Zhang, M., & Wu, K. (2021). Molecular advances in plant iron and zinc nutrition. *Frontiers in Plant Science*, 12, 647182.

Zhang, Y. Q., Sun, Y. X., Ye, Y. L., Karim, M. R., Xue, Y. F., Yan, P., Meng, Q. F., Cui, Z. L., Cakmak, I., Zhang, F. S., & Zou, C. Q. (2012). Zinc biofortification of wheat through fertilizer applications in different locations of China. *Field Crops Research*, 125, 1-7.

Zhang, Y., Shi, R., Rezaul, K. M., Zhang, F., & Zou, C. (2012). Zinc foliar application: A key strategy for improving grain zinc concentration in wheat. *Frontiers in Plant Science*, 3, 124.

Zou, C. Q., Zhang, Y. Q., Rashid, A., Ram, H., Savasli, E., Arisoy, R. Z., & Hassan, M. (2012). Biofortification of wheat with zinc through zinc fertilization in seven countries. *Plant and Soil*, 361(1-2),119-130.

تأثير معاملات الزنك على المحتوى الغذائي لبعض أصناف القمح المصري والروماني

محمد مصطفى الفولي[١]،ألينا لوراأجابي[٢]،مارينل نيكولا هورابلاجا[٢], سمير حسني شعبان[١]*، سيبريان بوزنة[٢]،عادل بدر النشرتي[١]،إيونوت راتش[٣]،محمد فاروق الدهشوري[١]،نيكولا تريتيان[٣]، روزاليا قادر[٣],هدى علي المناديلي[١]

١- قسم تكنولوجيا التسميد، المركز القومي للبحوث، ٣٣ ش البحوث (ش التحرير سابقا)، الدقي، الجيزة، الرمز البريدي: ١٢٦٢٢، مصر
٢- محطة البحث والتطوير الزراعي لوفرين، مقاطعة تيميس، رومانيا
٣- محطة البحث والتطوير الزراعي توردا، مقاطعة كلوج، رومانيا

خلال فصل الشتاء ٢٠٢٠/٢٠١٩، ٢٠٢١/٢٠٢٠، ٢٠٢٢/٢٠٢١ في مصر، تم اختيار موقعين يمثلان الترب الطينية والجيرية، حيث تزرع أصناف القمح وهي الجيزة ١٦٨، الجيزة ١٧١، والجميزة ١١. ورشت هذه الأصناف بكبريتات الزنك ٥ جم/لتر أثناء مرحلة الاستطالة (١) والمرحلة اللبنية (٢) و(المرحلة ١ و٢). لقد وجد أن مستوى الزنك في أوراق العلم بالجميزة ١١ والجيزة ١٧١ قد تحسن نتيجة الرش الورقي في مرحلتي االاستطالة واللبنية. وتفوق جيزة ١٧١ على جيزة ١٦٨ في نسبة الزنك في الحبوب والقش. ونتيجة لتأثير زيادة محتوى الزنك في الأوراق والحبوب والتبن تحسن محتوى بعض العناصر الغذائية الأخرى مثل N وP وCa وMg. وفي رومانيا، أجريت التجربة على أربعة أصناف: سيبريان، وجلوسا، وأندرادا، وبادوريني. عولجت هذه الأصناف بكبريتات الزنك وتشمل التربة ٣٠ كجم/هكتار قبل الزراعة ومعاملة البذور والرش الورقي بمحلول ٠٫٣% في مراحل مختلفة. وأدى الجمع بين نقع البذور وإضافة التربة والرش الورقي إلى ظهور تأثير أوضح على نسبة الزنك، واختلفت الأصناف في نسب الزيادة مع طريقة التطبيق.