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Response of wheat cultivars to zinc application for seed yield and quality improvement

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Abstract

Zinc deficiency is a common nutritional problem in calcareous agricultural soils, resulting in reduced crop yield and performance. The effects of zinc sulphate (0 and 40 kg/ha) on seed yield, its components and seed element contents of 21 wheat cultivars were investigated. Zinc sulphate application increased plant height, leaf area index (LAI), flag leaf area, biomass, spike length, number of seeds per spike, seed weight and harvest index (HI). The increase in HI indicates the greater effect of zinc on seed production compared to plant biomass. In most of the cultivars, zinc sulphate application decreased the content of phosphorus and nitrogen in seeds and increased the content of iron and potassium. The cultivars showed significant differences in all the traits measured, indicating the existence of genetic diversity in the cultivars studied. In the second year, which was hotter and drier than the first year, zinc sulphate application reduced the damage caused by drought and heat stress and improved seed yield and quality. The regression fit showed that newer cultivars had lower yields in unfertilized conditions compared to old cultivars and showed their superiority in zinc fertilized conditions. It seems that the newer varieties require more fertilizer because they have been bred on fertile soils.

Introduction

Wheat has the highest role in supplying human food in terms of high adaptability to a wide range of environmental conditions and the highest global production among other crops (Grote *et al.*, 2021). This crop is economically the most important cereal in the world (Anwar *et al.*, 2021). The economic importance of wheat and the increase in its consumption due to the growth of the world's population require strategies such as the introduction of high-yielding cultivars (Lima *et al.*, 2021) and the improvement of seed quality through better plant nutrition management or plant breeding (Sher *et al.*, 2022). Soil nutrient deficiency is a limiting factor for cereal production and quality in many countries, especially in developing countries (Joy *et al.*, 2017; Grote *et al.*, 2021).

Although zinc is an important component of many enzymes responsible for metabolic reactions in plants, zinc deficiency is one of the most important and widespread micronutrient deficiencies in the world, and its deficiency is a public problem among people in developing countries (Joy *et al.*, 2017). It has been reported that more than two billion people in developing countries suffer from zinc deficiency (Grote *et al.*, 2021). Zinc deficiency causes human immunodeficiency, stunted growth, hair loss, infertility and cognitive disorders (Ramazan *et al.*, 2020; Sher *et al.*, 2022). Calcareous soils, high bicarbonate of irrigation water, low soil organic matter and excessive use of phosphate fertilizers are among the reasons for zinc deficiency. The result of these factors causes zinc deficiency in the plant, decrease in yield, and decrease in nutritional value due to increase in the amount of phytic acid. These eventually cause zinc deficiency in the human society that uses these products (Sharma *et al.*, 2013). Wheat is a poor source of zinc for human nutrition, and the zinc content in most cultivars is less than 20 mg/kg, while its amount in the dry weight of wheat grains should be more than 50 mg/kg (Ghasal *et al.*, 2017). Zinc application increases seed yield and its quality, and also increases the shelf life of bread.

In plants, zinc plays a role in processes such as chlorophyll synthesis, indole-3-acetic acid biosynthetic pathway, chloroplast development, nitrogen metabolism, protein quality, and activation of enzymes such as carbonic anhydrase (Taiz and Zeiger, 2003; Sharma *et al.*, 2013; Anwar *et al.*, 2021). On the other hand, the application of micronutrients such as zinc increases the utilization efficiency of macronutrients and reduces their utilization costs (Sher *et al.*, 2022). In wheat, the application of zinc in the form of soil or foliar application improved the seed yield and its components, biological yield, gluten and zinc content (Afzal *et al.*, 2017; Anwar *et al.*, 2021; Sher *et al.*, 2022). It has been found that zinc application can cause accumulation of zinc in wheat seeds in high amounts (Ram *et al.*, 2016; Sher *et al.*, 2022). Different methods of zinc application show a positive effect on the zinc content of seeds (Afzal *et al.*, 2017; Ma *et al.*, 2017). Produced seeds show higher germination potential and growth rate, and reduce the concentration of pollutants such as cadmium in the edible parts of agricultural crops (Afzal *et al.*, 2017; Safari *et al.*, 2019; Anwar *et al.*, 2021).

Among cereals, wheat and rice are more susceptible to zinc deficiency, and a decrease in seed yield up to 80% along with a reduction in seed zinc content has been observed under zinc deficiency conditions (Singh *et al.*, 2005). According to Boostani *et al.* (2019), the total amount of zinc in calcareous soils of Iran is sufficient (50 to 300 mg/kg), but its concentration in soil solution and consequently its bioavailability is very low due to the soil conditions such as high pH, low organic matter and high calcium carbonate. These factors have led to the failure of most crops, such as cereals, to achieve high yields. The objectives of this experiment were (1) to study the response of different wheat cultivars introduced in the last 50 years to soil application of zinc sulphate, (2) to identify the cultivar or cultivars with high seed yield under conditions of supplemental zinc supply or zinc deficiency, and (3) to study the effect of zinc on seed yield and its components and seed quality of the cultivars studied.

Materials and methods

Experimental design, plant material and zinc treatment

The field experiment was conducted as a split-block, randomized complete block design with three replications in two consecutive cropping years (2018 and 2019). The experimental treatments included zinc application from zinc sulphate source (33% purity, Kimia Pars Shayankar, Iran) at two levels (0 and 40 kg/ha) as the first factor and 21 wheat cultivars as the second factor. The cultivars studied with their year of release are presented in Table 1. The seeds of these cultivars were obtained from the Seed and Plant Improvement Institute, Karaj, Iran. Zinc sulphate was applied to the field in the form of solution with irrigation water two times with the first and second irrigation after planting.

Field preparation and seed cultivation

Seedbed preparation included spring ploughing, disking, and levelling prior to fall planting. Half of the nitrogen (urea fertilizer, Shiraz Petrochemical Co., Iran) was applied at the three to four leaf stage and the rest before stem elongation. Potassium (potassium sulphate, Khadamat hemayti Co., Iran) and phosphorus (triple superphosphate, Khadamat hemayti Co., Iran) fertilizers were completely spread on the field before planting at the rate of 100 kg/ha. The physicochemical characteristics of the soil of the research station are presented in Table 2. The ambrothermic diagrams of the research station of the University of Zanjan are presented in Fig. 1 for two cropping years (2018 and 2019). Seed sowing was carried out using a linear research seed sowing machine (Wintersteiger tool carrier 2700, Austria) in the research farm of the Faculty of Agriculture, University of Zanjan, Zanjan, Iran (located at 36°41′ N latitude, 48°27′ E longitude, and 1620 m above sea level). The sowing depth was 4–5 cm. The date of

Table 1. Wheat cultivars' names and years of their release studied under zinc application conditions and two cropping years of 2018–2019

Cultivar	Introduction year	Plant height (cm)	Growth type	Maturity time
Khalij	1960	115	Spring	Early ripening
Inia	1968	105	Intermediate	Early ripening
Moghan1	1973	90	Spring	Relatively early ripening
Karaj2	1973	105	Intermediate	Semi-late ripening
Khazar1	1973	105	Spring	Early ripening
Moghan2	1974	87.5	Spring	Relatively early ripening
Chenab	1975	Dwarf (60–70)	Spring	Early ripening
Karaj3	1976	110	Winter	Intermediate ripening
Bayat	1976	Intermediate (85–100)	Spring	Relatively early ripening
Golestan	1986	110	Spring	Little late ripening
Falat	1990	Relatively dwarf (85–90)	Spring	Relatively early ripening
Navid	1990	100	Winter	Semi-late ripening
Hirmand	1991	100	Spring	Early ripening
Alamoot	1995	100	Winter	Late ripening
Seymareh	1996	95	Spring	Early ripening
Zagros	1997	103	Spring	Early ripening
Kouhdasht	2000	92	Spring	Early ripening
Pishtaz	2002	92	Spring	Relatively early ripening
Toos	2002	110	Intermediate	Relatively late ripening
Moghan3	2006	100	Spring	Intermediate ripening
Sirvan	2006	94	Spring	Early ripening

Table 2. Physico-chemical properties of soil at a depth of 0–30 cm in the Research Farm of the University of Zanjan

Soil texture	Organic matter (g/kg)	Nitrogen (g/kg)	Phosphorus (mg/kg)	Potassium (g/kg)	Zinc (mg/kg)	Calcium (g/kg)	Electrical conductivity (dS/m)	pH
Clay loam	8.40	0.70	9.60	0.21	0.81	0.13	0.48	7.90

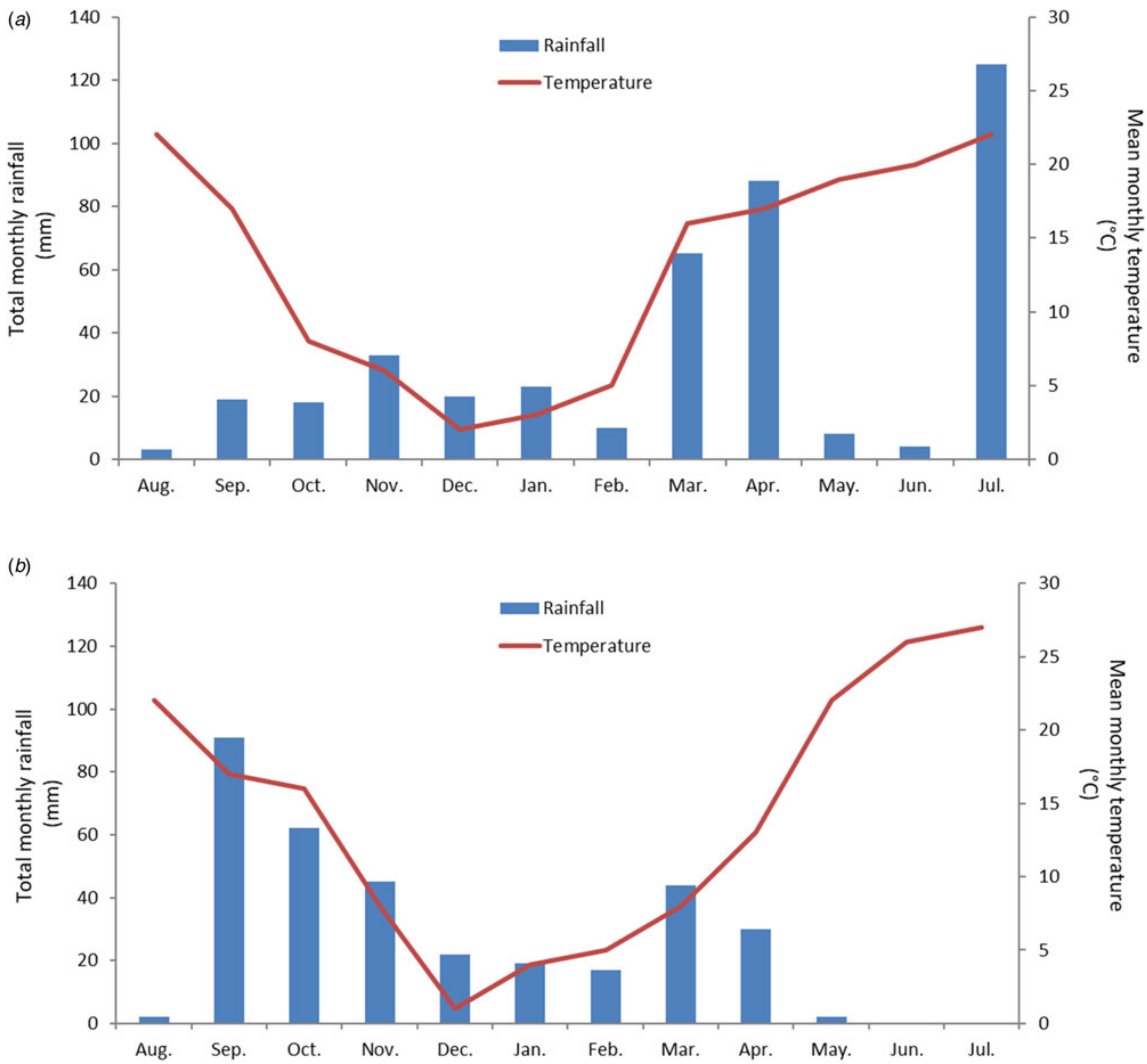

Figure 1. Monthly mean temperature and monthly total precipitation from August through July for 2018–2019 (a) and 2019–2020 (b).

planting in both years (2018 and 2019) was October 23. Before sowing, the seeds were disinfected with carboxin-thiram fungicide. Each experimental plot consisted of four rows. The distance between rows was 20 cm and the length was 4 m. The distance between plots and blocks was set to 50 and 100 cm, respectively. Irrigation was done once a week with an irrigation brigade tape. Weeds were controlled by frequent manual weeding during the growing season. Deltamethrin (Decis, EC 2.5%, Gyah Co. Iran) and propiconazole (Tilt, EC 25%, Gyah Co. Iran) were applied in late April or May to control sunn pest (*Eurygaster integriceps*) and rust (*Puccinia triticina*).

Leaf area index and flag leaf area (FLA)

At the flowering stage, all plants were removed from 0.5 m^2 and the total leaf area was determined using a leaf area metre (Delta T Device LTD, England). Then, the leaf area index (LAI), which is expressed as the ratio of leaf area to ground area (Hunt,

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1982), was calculated for each of the experimental units. Also, the FLA of the plants was recorded separately and reported in cm^2.

Chlorophyll content index

The greenness of the plants was measured non-destructively using a chlorophyll meter (CCM200-OPTI SCIENCE.UK) at the heading stage. In each experimental plot, 10 plants were randomly selected, and greenness was measured for the main stem flag leaf.

Plant height and spike length

At maturity, the height of 10 plants from the ground to the end of the spike was measured and recorded. For the same plants, the length of the spike was also measured from the part of the spike node to the end of the spike.

The number of seeds per spike, 1000-seed weight, biological and seed yield and harvest index

The plants were harvested at maturity and when the plants turned yellow. On one m^2 of each plot, all plants were cut, and the number of spikelets was counted. After crushing the spike, seeds were counted using a seed counter (Pfeuffer, Germany). The number of seeds per spike was obtained by dividing the number of seeds by the number of spikes. The remaining area of the plot was harvested with a research combine and after weighing all harvested plants, the biological yield (t/ha) was recorded. The harvest index (HI) was calculated by dividing the harvested seeds by the biological yield. The 1000 seed weight was obtained by averaging 1000 seed weight of four samples for each plot.

Seed quality parameters: nitrogen, phosphorus, potassium, zinc, and iron content

Seed nitrogen content was determined by the standard Kjeldahl method (Hanon Auto Kjeldahl Distiller, K9840, Germany). Sulphuric acid and a catalyst mixture of copper sulphate and potassium sulphate were used to digest the sample (0.3 g dry sample). The nitrogen content was expressed as a percentage (Andrews and Newman, 1968). To determine the content of phosphorus, potassium, zinc and iron, the method of digesting the plant sample (0.3 g of dry sample) with mixed acid (6 g of salicylic acid, 100 ml of 98% sulphuric acid and 18 ml of distilled water) was used (Walinga *et al.*, 1995). The amount of potassium in the obtained extract was read by the method of flame measurement (flame photometry) using a flame photometer (Jenway, model PFP7/C, UK) and expressed as a percentage (Soloman *et al.*, 1986). The amount of phosphorus was measured by the yellow calorimetric method using ammonium vanadate molybdate reagent with a spectrophotometer (PerkinElmer, Lambada 25, USA) at a wavelength of 470 nm and reported as a percentage (Chapman and Pratt, 1961). Also, the concentration of iron and zinc elements was measured in the obtained extract using an atomic absorption spectrometer (Varian 220 AA, Australia) and the final concentration was determined.

Statistical analysis

A combined analysis of variance was carried out for the split-block experiment in a basic design of randomized complete blocks over two years in all traits. The data were checked for normality before statistical analysis. Statistical analysis and mean comparison were done using SAS 9.1 program. Data mean comparisons were performed by the least significant difference test (LSD, $P \leq 0.05$). The linear regression between seed yield and the introduction year of cultivars and between LAI and seed yield was fitted in both conditions of non-application and application of zinc sulphate.

Results

The results of ANOVA showed that LAI, FLA, chlorophyll content index, plant height, spike length, biological yield, seed yield, HI, 1000 seed weight, number of seeds per spike, and amount of nitrogen, phosphorus, potassium, and iron in seed were significantly affected by the simple effects of year, zinc sulphate, and cultivar, but the amount of zinc in wheat seed was only affected by the simple effect of cultivar (Table 3).

LAI and FLA

In the first year (2018), the highest LAI was associated with Sirvan, Alamoot, Bayat, Falat, Chanab and Khalij cultivars (Table 4). In the second year (2019), the highest LAI was observed in Sirvan, Alamoot, Moghan2 and Moghan1 cultivars. The lowest LAI in the first year was observed in cultivar Pishtaz. In the second year, Karaj2 and Golestan showed the lowest LAI (Table 4). In general, the highest LAI was found in the high yielding cultivars in both years and under either zinc sulphate application or no application conditions (Tables 4 and 5; and Fig. 3). In both years, Falat and Moghan3 cultivars had the highest and lowest FLA, respectively. When comparing the two years, the highest FLA (34.7 cm^2) was associated with cultivar Falat in the first year (Table 4). In all cultivars, the values of LAI and FLA showed a decremental trend in the second year compared to the first year (Table 4). Zinc sulphate application increased LAI and FLA in all wheat cultivars compared to the non-application conditions (Table 5). The highest values of LAI and FLA were obtained with the application of zinc sulphate in cultivar Falat. The lowest LAI and FLA were observed in Chenab and Moghan3 cultivars, respectively, under the non-application of zinc sulphate condition (Table 5). Linear regressions between seed yield and years of experiment showed that leaf area was higher in the first year than in the second year and the highest LAI was above 5 in the first year. This increase in LAI was achieved with the increase in seed yield and the maximum seed yield was over seven t/ha. But in the second year as a hot and dry year, LAI decreased in all cultivars and the maximum LAI was near to 4.7, therefore the maximum seed yield was reduced to near to 6.4 t/ha (Figs 3 (a) and (b)). A similar trend was found between LAI and zinc sulphate application condition (Figs 3(c) and (d)). In fact, the application of zinc sulphate increased the LAI values, and in high yielding varieties, LAI showed a greater increase than for other varieties.

Chlorophyll content index (CCI)

Golestan and Khalij cultivars had the highest CCI in the first year, and in the second year, Khalij again had the highest CCI compared to other cultivars. The lowest CCI was observed in Moghan2 in the first year and in Moghan3 in the second year. In the second year, the CCI decreased in all the varieties studied

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Table 3. Analysis of variance of zinc sulphate treatment and cultivar on the studied traits of wheat in two cropping years

		Mean of squares							
S.O.V	df	Leaf area index	Flag leaf area	Chlorophyll index	Plant height	Spike length	Biological yield	Seed yield	Harvest index
Year	1	0.5540766*	300.296**	4277.219**	287.04**	418.244**	96.869**	25.005*	138.651*
Rep(Year)	4	0.1427541	11.942	22.027	93.713*	2.487	1.29	0.3664	4.208
Zn	1	28.6357151**	162.161*	1092.001**	2682.264**	40.184**	604.162**	171.493**	916.15**
Zn × Year	1	0.0001903	0.0016	51.337	987.505**	44.478**	0.0000001	0.0000001	3.01
E(a)	4	0.0717781	8.591	19.329	8.331	0.462	1.434	1.289	17.404
Cultivar	20	5.5605739**	228.924**	132.065**	313.188**	7.175**	78.088**	9.384**	82.257**
Cultivar × Year	20	0.0005179	0.0536	80.369**	294.762**	5.596**	0.0000001	0.0000001	0.1915
E(b)	80	0.0752931	1.617	9.067	14.92	1.501	2.152	0.8329	10.924
Zn × Cultivar	20	0.9065475**	4.719	15.164494*	35.177	1.28	17.36**	7.263**	89.886**
Zn × Cultivar × Year	20	0.0005905	0.0072	9.017	37.442*	1.162	0.0000001	0.0000001	0.123
E(ab)	80	0.0808775	3.189	7.492	20.946	1.315	2.62	0.6737	11.897
CV (%)		12.6	8.3	8.3	5.8	10.3	7.6	14.6	13.1

		Mean of squares						
S.O.V	df	1000-seed weight	Number of seeds per spike	Seed N	Seed P	Seed K	Seed Zn	Seed Fe
Year	1	5008.05**	332.442**	5.655**	0.0262**	0.0555**	0.00061122	0.00131**
Rep(Year)	4	12.935	0.448	1.6911**	0.0375**	0.0682**	0.00055145	0.00161**
Zn	1	600.48**	1017.46**	3.1401**	0.00005*	0.0459**	0.0005409	0.00109**
Zn × Year	1	1.402	0.1813	0.000248	0.00001	0.000006	0.00000002	0.00000015
E(a)	4	6.852	1.664	0.0000885	0.000003	0.000008	0.00009481	0.00000018
Cultivar	20	147.344**	1412.28**	0.47938**	0.0044**	0.0101**	0.000086**	0.00024**
Cultivar × Year	20	83.171**	0.2488	0.000195	0.000003	0.000006	0.0000078	0.00000015
E(b)	80	4.49	4.699	0.000192	0.000006	0.000004	0.0000075	0.00000009
Zn × Cultivar	20	7.287	35.993**	0.2978**	0.0049**	0.0069**	0.00008**	0.00016**
Zn × Cultivar × Year	20	12.153**	0.2108	0.000183	0.000003	0.000005	0.0000064	0.00000011
E(ab)	80	5.25	3.323	0.000191	0.000006	0.000005	0.0000083	0.00000011
CV (%)		6.7	5.1	0.5	0.7	0.5	4.5	0.5

*, $P \leq 0.05$; **, $P \leq 0.01$; ns, not significant.

except Toos (Table 4). The application of zinc sulphate increased the CCI values in the wheat cultivars compared to the non-application of zinc sulphate (Table 5).

Plant height and spike length

In the first year, the highest plant height belonged to the cultivars Inia (99 cm) and Khalij (98 cm) (Table 4). In the second year, Karaj2 (91 cm) showed the highest height. The lowest height was associated with the cultivar Bayat in both years (Table 4). In the second year, the height of Moghan3, Alamoot, Sirvan, Chenab, Navid, Karaj2, Karaj3 and Hirmand cultivars increased compared to the first year, while it decreased in other cultivars (Table 4). Plant height of cultivars increased with zinc sulphate application (Table 5).

In the first year, the spike length of Moghan1, Kouhdasht, Golestan and Sirvan was higher compared to the other varieties, among which Moghan1 had the longest spike. In the second year, the highest spike length was observed in Toos, Kouhdasht and Golestan cultivars. The lowest spike length was obtained in the first year in cultivar Falat and in the second year in cultivar Seymareh (Table 4). Spike length decreased in the second year (Table 4). Application of zinc sulphate increased the spike length in all wheat cultivars compared to non-application of zinc sulphate (Table 5). The maximum spike length was obtained in cultivar Kouhdasht with zinc sulphate application. The lowest spike length was obtained in Seymareh and Falat cultivars in non-application of zinc sulphate condition (Table 5).

Biological yield, seed yield, and HI

In both years, Sirvan had the highest biological yield, which was not significantly different from Alamoot and Moghan2. In both years, Pishtaz showed lower biological yield than other varieties (Table 4). The biological yield of all cultivars in the second year showed a decrease of about 3.5 to 7% compared to the first

Table 4. Mean comparison of the leaf area index, flag leaf area, chlorophyll index, plant height, spike length, biological yield, and seed yield of different wheat cultivars in two cropping years

	Leaf area index		Flag leaf area (cm^2)		Chlorophyll index		Plant height (cm)		Spike length (cm)		Biological yield (t/ha)		Seed yield (t/ha)	
Cultivar	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Khalij	4.6	3.5	28.8	26.5	42.2	37.3	97.8	84.7	13.0	9.0	20.8	19.6	5.9	5.3
Inia	4.2	3.2	22.4	20.2	33.4	29.8	99.0	79.0	13.3	9.9	22.9	21.7	6.1	5.4
Moghan1	4.2	4.0	17.5	15.5	39.2	31.5	81.4	73.6	14.2	9.9	23.4	22.2	7.3	6.6
Karaj2	2.9	1.8	27.4	25.2	37.2	25.6	72.9	91.5	11.6	10.4	18.2	17.0	5.0	4.4
Khazar1	2.9	1.8	22.1	20.0	34.9	34.8	79.0	70.6	12.7	9.7	23.3	22.1	5.1	4.4
Moghan2	4.1	4.0	19.2	17.0	31.1	30.3	79.3	77.0	10.0	9.7	25.7	24.5	7.7	7.0
Chenab	4.6	3.5	25.2	23.0	37.9	30.3	71.3	78.0	11.2	10.3	22.9	21.7	6.6	6.0
Karaj3	2.3	1.5	17.7	15.7	35.4	28.8	76.0	78.0	11.2	10.2	18.7	17.5	4.9	4.3
Bayat	4.8	3.7	19.6	17.4	40.7	31.1	67.4	85.7	13.0	9.8	23.6	22.3	6.6	6.0
Golestan	2.6	1.5	20.6	18.4	43.6	34.0	81.3	76.9	13.6	10.1	20.3	19.1	5.2	4.6
Falat	4.6	3.5	34.7	32.1	34.4	23.9	82.1	71.1	9.6	8.7	20.4	19.1	6.2	5.5
Navid	3.1	3.0	25.7	23.4	37.8	25.1	75.6	78.4	11.7	8.8	19.0	17.7	5.6	5.0
Hirmand	2.6	2.5	23.5	21.3	35.5	24.2	76.8	81.7	12.0	10.4	19.8	18.6	5.1	4.4
Alamoot	4.8	4.1	21.7	19.5	34.8	26.8	80.3	84.7	13.0	10.6	26.1	24.9	6.7	6.1
Seymareh	3.2	3.4	24.8	22.6	41.9	22.6	73.7	72.7	12.5	7.9	21.8	20.5	5.8	5.1
Zagros	2.8	2.1	18.5	16.3	31.6	26.5	82.1	71.9	13.2	9.3	21.1	19.9	5.5	4.9
Kouhdasht	3.8	3.3	21.8	19.6	37.6	22.8	81.3	71.2	13.8	10.6	23.1	21.9	6.6	6.0
Pishtaz	2.1	2.2	23.0	20.8	41.0	30.2	87.6	73.7	11.8	10.5	17.9	16.6	4.1	3.5
Toos	3.3	2.7	24.6	22.5	33.2	34.6	90.7	86.2	12.2	11.6	22.8	21.6	5.8	5.2
Moghan3	4.4	3.4	14.7	12.8	34.1	19.3	74.6	76.4	13.4	9.7	19.8	18.6	6.2	5.6
Sirvan	5.0	4.7	21.1	18.9	38.4	33.5	71.3	73.8	13.6	9.7	26.7	25.4	7.1	6.4
LSD (5%)	0.2206		1.022		2.421		3.106		0.985		1.179		0.734	

Table 5. Mean comparison of the leaf area index, flag leaf area, chlorophyll index, plant height, spike length, biological yield, and seed yield in different wheat cultivars was affected by zinc sulphate treatment

	Leaf area index		Flag leaf area (cm^2)		Chlorophyll index		Plant height (cm)		Spike length (cm)		Biological yield (t/ha)		Seed yield (t/ha)	
$ZnSO_4$	–	+	–	+	–	+	–	+	–	+	–	+	–	+
Khalij	3.4	4.0	27.0	28.3	34.2	45.3	85.9	96.5	10.6	11.4	20.5	19.9	5.5	5.8
Inia	3.0	4.1	19.8	22.9	29.6	33.6	87.2	90.8	11.2	12.0	20.6	24.0	5.2	6.4
Moghan1	4.0	4.6	15.9	17.1	34.1	36.6	72.9	82.1	11.8	12.3	21.5	24.1	6.5	7.4
Karaj2	2.6	2.2	25.4	27.0	30.1	32.7	78.2	86.2	10.4	11.5	16.4	18.8	5.0	5.0
Khazar1	2.2	3.9	21.0	21.1	33.4	36.2	73.7	76.0	10.8	11.5	20.6	24.7	3.4	6.1
Moghan2	4.0	4.6	17.9	18.3	29.9	31.4	74.3	82.0	9.4	10.3	23.7	26.5	6.6	8.0
Chenab	3.2	4.1	23.5	24.7	32.0	36.1	73.1	76.2	10.6	11.0	21.6	23.0	5.1	7.5
Karaj3	2.4	1.7	16.8	16.8	29.8	34.4	73.0	81.0	9.9	11.6	17.9	18.3	4.5	4.7
Bayat	2.7	4.0	17.9	19.0	32.6	39.1	74.0	79.1	11.3	11.5	20.1	25.8	5.7	6.9
Golestan	1.3	3.8	19.0	20.1	37.0	40.6	77.4	80.9	11.2	12.4	16.8	22.6	3.1	6.7
Falat	3.8	4.3	31.5	35.3	28.2	30.0	73.1	80.1	9.0	9.3	20.0	19.5	6.0	6.0
Navid	1.8	3.3	24.1	24.9	30.7	32.2	73.7	80.2	9.8	10.6	18.0	18.7	4.6	5.9
Hirmand	1.8	3.3	21.6	23.2	28.0	31.7	78.3	80.2	11.2	11.3	16.5	21.9	4.1	5.4
Alamoot	1.4	4.7	18.6	22.6	28.0	33.6	78.4	86.6	11.5	12.1	24.3	26.7	4.2	8.5
Seymareh	2.8	4.0	23.2	24.2	28.9	35.5	71.1	75.3	9.5	11.3	19.7	22.6	4.2	6.8
Zagros	2.1	2.8	16.0	18.8	27.4	30.7	73.0	81.0	11.0	11.5	19.1	22.0	5.0	5.4
Kouhdasht	3.8	3.9	19.9	21.6	27.1	33.2	70.0	82.5	11.6	12.8	22.2	22.9	6.2	6.4
Pishtaz	2.2	2.4	20.4	23.4	32.6	38.6	76.1	85.1	10.8	11.4	15.8	18.7	3.4	4.2
Toos	2.8	3.8	21.9	25.2	32.8	35.0	82.1	94.8	12.3	12.5	20.2	24.1	4.5	6.5
Moghan3	2.1	4.2	13.4	14.0	24.9	28.4	72.5	78.5	11.0	12.2	15.6	22.8	3.9	8.0
Sirvan	1.9	4.5	20.0	20.0	34.0	37.9	72.7	74.7	10.9	12.4	21.8	30.2	4.2	9.3
LSD (5%)	0.2287		1.436		2.201		3.680		0.922		1.301		0.660	

year (Table 4). The results of the interaction of zinc sulphate and cultivar showed that under no zinc sulphate application conditions, the highest and lowest biological yields were associated with Alamoot and Moghan3 cultivars, respectively. While under zinc sulphate application conditions, the highest and lowest values were observed in Sirvan and Karaj3 cultivars, respectively (Table 5).

In both years, Moghan2 had the highest seed yield compared to other varieties and there was no significant difference with Moghan1 variety. In contrast, Pishtaz had the lowest seed yield in both years (Table 4). Seed yield in the second year was about 8–16% lower than in the first year (Table 4). Zinc sulphate application resulted in an increase in seed yield in all wheat cultivars. The highest rate of increase (118.5%) was observed in cultivar Sirvan (Table 5).

The highest HI in both years was found in Moghan1 and had no significant difference from Moghan3 and Falat cultivars. On the other hand, the lowest HI was obtained from Khazar1 cultivar, which had no significant difference from Pishtaz cultivar in both years. In the second year, the HI of all cultivars showed a decreasing trend compared to the first year (Table 6). In general and with some exceptions, zinc sulphate application showed an incremental effect on HI (Table 7). The highest HI was related to the cultivar Moghan3 with the application of zinc sulphate and the lowest value was obtained in the cultivar Khazar1 under non-application of zinc sulphate (Table 7).

The number of seeds per spike and the 1000-seed weight

In both years, the maximum number of seeds per spike was obtained in Moghan1 and Seymareh cultivars and the lowest value without significant differences was found in Pishtaz and Falat cultivars in both years. In all cultivars, the number of seeds per spike decreased in the second year compared to the first year (Table 6). Application of zinc sulphate increased the number of seeds per spike by 2–20% in the cultivars studied (Table 7).

In the first year, Khalij and then Sirvan cultivars had more 1000 seed weight compared to other cultivars, while in the second year, higher 1000 seed weight was obtained in Sirvan, Kouhdasht and Seymareh cultivars, respectively. On the other hand, the lowest 1000 seed weight in the first year was associated with Karaj3 cultivar, while in the second year Toos showed the lowest 1000 seed weight and had no significant differences with Alamoot and Karaj3 cultivars (Table 6). In all cultivars studied, the 1000 seed weight decreased by 4–40% in the second year compared to the first year (Table 6), but the seed weight increased with zinc sulphate application in all cultivars (Table 7). The highest 1000-seed weight was related to the variety Sirvan with zinc sulphate application and

Table 6. Mean comparison of harvest index, 1000-seed weight, number of seeds per spike, and seed N, P, K, Zn, and Fe contents of different wheat cultivars in two cropping years

	Harvest index (%)		1000-seed weight (g)		Number of seeds per spike		Seed N (%)		Seed P (%)		Seed K (%)		Seed Zn (mg/g)		Seed Fe (mg/g)	
Cultivar	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Khalij	28.6	27.2	49.3	34.6	39.0	36.7	2.6	2.3	0.41	0.39	0.43	0.40	0.067	0.065	0.066	0.061
Inia	26.6	25.2	38.1	30.3	26.6	24.4	2.7	2.4	0.39	0.37	0.43	0.40	0.065	0.062	0.066	0.061
Moghan1	30.9	29.8	38.3	27.3	53.8	50.5	3.0	2.7	0.36	0.34	0.44	0.41	0.063	0.057	0.067	0.063
Karaj2	27.7	25.9	36.8	27.9	24.7	22.7	3.4	3.1	0.41	0.39	0.52	0.49	0.068	0.065	0.079	0.075
Khazar1	21.8	19.5	36.3	30.3	32.1	29.8	2.9	2.6	0.39	0.37	0.40	0.37	0.065	0.061	0.061	0.056
Moghan2	29.9	28.7	38.7	29.7	29.7	27.4	2.7	2.4	0.39	0.37	0.46	0.43	0.065	0.062	0.071	0.066
Chenab	28.6	27.3	37.9	30.0	47.2	45.8	3.0	2.7	0.39	0.37	0.40	0.37	0.064	0.062	0.061	0.056
Karaj3	26.3	24.5	27.2	24.9	43.6	41.3	3.0	2.7	0.38	0.36	0.47	0.44	0.070	0.062	0.072	0.067
Bayat	28.4	27.2	32.4	29.9	25.2	22.9	3.0	2.7	0.37	0.35	0.41	0.38	0.064	0.062	0.063	0.058
Golestan	25.0	23.2	34.2	32.8	29.0	26.8	2.7	2.4	0.39	0.37	0.43	0.40	0.064	0.064	0.066	0.061
Falat	30.2	28.9	42.2	30.5	24.5	21.1	2.7	2.4	0.35	0.33	0.44	0.41	0.056	0.055	0.067	0.063
Navid	29.3	27.8	40.6	28.6	48.2	45.8	2.9	2.6	0.36	0.34	0.42	0.39	0.061	0.058	0.063	0.059
Hirmand	25.5	23.8	39.3	31.5	26.4	24.3	2.9	2.6	0.39	0.37	0.40	0.37	0.067	0.063	0.061	0.056
Alamoot	25.2	24.0	37.6	23.6	49.4	46.9	2.9	2.6	0.40	0.38	0.44	0.41	0.065	0.063	0.067	0.063
Seymareh	26.3	24.8	37.5	35.5	51.3	49.0	3.0	2.7	0.37	0.35	0.42	0.39	0.061	0.058	0.063	0.059
Zagros	26.2	24.7	39.4	29.6	26.4	24.3	3.3	3.0	0.40	0.38	0.45	0.42	0.066	0.063	0.068	0.064
Kouhdasht	28.5	27.3	36.2	35.7	31.5	29.3	3.2	2.9	0.40	0.38	0.41	0.38	0.067	0.063	0.063	0.058
Pishtaz	22.8	20.7	36.5	28.3	24.4	22.5	3.1	2.8	0.35	0.33	0.43	0.40	0.062	0.059	0.065	0.061
Toos	25.1	23.6	42.0	22.7	41.8	39.5	3.1	2.8	0.38	0.36	0.44	0.41	0.063	0.061	0.067	0.063
Moghan3	30.6	29.1	45.1	27.1	49.9	47.7	3.0	2.7	0.40	0.38	0.47	0.44	0.066	0.063	0.072	0.067
Sirvan	25.6	24.3	48.2	36.2	49.3	46.8	2.9	2.5	0.41	0.39	0.46	0.43	0.067	0.064	0.070	0.066
LSD (5%)	2.658		1.704		1.743		0.0111		0.0019		0.0015		0.0022		0.00024	

Table 7. Mean comparison of harvest index, 1000-seed weight, number of seeds per spike, and seed N, P, K, Zn, and Fe contents in different wheat cultivars was affected by zinc sulphate treatment

	Harvest index (%)		1000-seed weight (g)		Number of seeds per spike		Seed N (%)		Seed P (%)		Seed K (%)		Seed Zn (mg/g)		Seed Fe (mg/g)	
$ZnSO_4$	–	+	–	+	–	+	–	+	–	+	–	+	–	+	–	+
Khalij	26.690	29.042	40.966	42.966	36.870	38.870	2.700	2.270	0.400	0.390	0.386	0.445	0.066	0.066	0.059	0.068
Inia	25.152	26.623	33.316	35.100	24.313	26.646	2.540	2.527	0.400	0.360	0.385	0.445	0.066	0.061	0.059	0.068
Moghan1	30.138	30.481	31.200	34.466	43.133	50.196	2.740	2.920	0.322	0.370	0.386	0.465	0.053	0.067	0.059	0.071
Karaj2	29.910	23.529	30.866	33.816	22.246	25.176	3.200	3.220	0.370	0.430	0.443	0.565	0.061	0.071	0.068	0.086
Khazar1	16.439	24.330	31.783	34.833	29.570	32.260	3.040	2.480	0.380	0.370	0.385	0.385	0.063	0.064	0.059	0.059
Moghan2	27.977	30.555	32.383	35.616	26.293	30.743	2.370	2.670	0.362	0.400	0.446	0.446	0.060	0.067	0.068	0.068
Chenab	23.360	32.509	32.016	35.850	47.243	56.753	3.273	2.470	0.370	0.390	0.385	0.385	0.061	0.065	0.059	0.059
Karaj3	25.195	25.559	25.033	26.983	34.870	50.053	2.910	2.690	0.400	0.340	0.445	0.465	0.066	0.066	0.068	0.071
Bayat	28.647	26.921	31.833	30.400	23.746	24.293	3.040	2.560	0.390	0.320	0.405	0.385	0.064	0.061	0.062	0.059
Golestan	18.507	29.673	31.433	35.466	26.903	28.903	2.810	2.360	0.400	0.350	0.445	0.385	0.066	0.062	0.068	0.059
Falat	29.829	30.690	35.900	36.850	21.073	24.580	2.400	2.630	0.310	0.360	0.401	0.445	0.051	0.061	0.061	0.068
Navid	25.577	31.413	33.150	35.966	45.003	49.010	2.840	2.600	0.340	0.360	0.355	0.445	0.056	0.063	0.054	0.068
Hirmand	24.884	24.305	33.700	37.166	24.080	26.580	2.970	2.460	0.393	0.370	0.385	0.385	0.065	0.065	0.059	0.059
Alamoot	17.277	31.828	28.766	32.450	44.193	52.116	2.912	2.560	0.380	0.390	0.403	0.445	0.063	0.065	0.062	0.068
Seymareh	21.162	29.868	34.183	38.733	49.243	51.023	3.078	2.670	0.338	0.380	0.355	0.445	0.056	0.063	0.054	0.068
Zagros	26.273	24.750	33.466	35.516	24.293	26.353	3.228	3.000	0.370	0.410	0.405	0.463	0.061	0.068	0.062	0.071
Kouhdasht	28.002	27.799	33.783	38.150	29.200	31.666	3.072	3.040	0.400	0.380	0.385	0.405	0.066	0.065	0.059	0.062
Pishtaz	21.543	21.994	29.500	35.266	22.960	23.953	3.180	2.800	0.362	0.320	0.443	0.385	0.059	0.062	0.068	0.059
Toos	21.785	26.962	30.000	34.616	39.563	41.743	3.200	2.610	0.390	0.340	0.405	0.445	0.064	0.061	0.062	0.068
Moghan3	24.929	34.802	34.533	37.633	45.723	51.866	2.810	2.810	0.382	0.400	0.463	0.445	0.063	0.067	0.071	0.068
Sirvan	19.359	30.598	39.800	44.600	46.956	49.083	2.532	2.810	0.390	0.400	0.443	0.445	0.065	0.067	0.068	0.068
LSD (5%)	2.773		1.842		1.466		0.0111		0.0019		0.0017		0.002		0.00026	

the lowest value was obtained in the variety Karaj3 without zinc sulphate application.

Seed nitrogen, phosphorus, potassium, zinc and iron content

The results of elemental analysis of seeds showed that the amount of these elements was higher in Karaj2 cultivar than in other cultivars in both years. In the first year, the maximum amount of zinc in wheat grains was associated with Karaj3 and Karaj2 cultivars, and in the second year it was associated with Karaj2 cultivar (Table 6). In both years, the lowest amount of seed nitrogen was obtained in Khalij and the lowest content of phosphorus and zinc was found in Falat cultivar. Also, Hirmand, Chenab and Khazar1 cultivars showed the lowest amount of potassium and iron content in both years (Table 6). In all cultivars, the amount of nitrogen, phosphorus, potassium, zinc and iron decreased in the second year compared to the first year (Table 6). Zinc sulphate application caused an increase in seed nitrogen content in cultivars Falat, Moghan1, Moghan2, Sirvan, and Karaj2, while there was no change in cultivar Moghan3 and a tendency to decrease in other wheat cultivars (Table 7). The highest amount of seed phosphorus was associated with the Karaj2 cultivar under zinc sulphate application, and the lowest amount was obtained in the Falat cultivar without zinc sulphate application conditions (Table 7). Zinc sulphate application in all wheat cultivars except Pishtaz, Bayat, Moghan3 and Golestan cultivars had a positive effect on the amount of potassium and iron elements (Table 7). The interaction effect of zinc and cultivar on the seed zinc content was significant. This shows wheat cultivars' different responses to zinc sulphate application in terms of seed zinc content. Surprisingly, application of zinc sulphate caused a decrease in seed zinc content in Bayat, Toos, Inia, Kouhdasht and Golestan cultivars compared to non-application of zinc sulphate, while there was no change in Khalij, Karaj3 and Hirmand cultivars and an increasing trend in other wheat cultivars, Moghan1, Karaj2, Moghan2, Chenab, Falat, Navid, Seymareh, Zagros, Pishtaz, and Moghan3 (Table 7). This could be due to different genetic potential in wheat cultivars. In general, the highest amount of nitrogen, phosphorus, potassium, zinc and iron in seeds was obtained in cultivar Karaj2 with zinc sulphate application and their contents were increased compared to the non-application of zinc sulphate (Table 7).

The trend of seed yield during the years of introduction

Linear regressions were fitted between seed yield and cultivar release year to evaluate the trend of seed yield of cultivars during the release years. The linear regression in zinc sulphate-free conditions showed that seed yield decreased significantly from about 5.5 to about 4.2 t/ha for cultivars released from 1960 to 2006. In fact, newer cultivars (e.g., Sirvan and Moghan3) had lower seed yields and older cultivars (e.g., Khalij and Inia) had higher seed yields under low zinc soil conditions. Under these conditions, the estimated reduction was 28 kg/ha per year (Fig. 2(a)). In contrast, the fitted linear regression between seed yield of wheat cultivars and year of cultivar adoption under zinc sulphate application conditions showed that seed yield increased linearly from about 6 t/ha to about 6.8 t/ha during the 45 years of cultivar adoption. In fact, under zinc sulphate application, relatively new varieties (Sirvan and Moghan3) had higher seed yields than older varieties (Khalij and Inia). Under these conditions, the estimated increase was 18 kg/ha per year (Fig. 2(b)).

Discussion

After the Green Revolution, wheat yield showed a dramatic increase, half of which was due to genetic improvement and the other half to appropriate agronomic practices (del Pozo *et al.*, 2016). In addition to genetic differences between wheat cultivars, which can also show significant variations in productivity potential, wheat growth can be affected by several environmental factors. Changes in growth conditions, such as nutrient application, can have a significant effect on plant growth and performance (Sher *et al.*, 2022). Our results indicated high genetic diversity among wheat cultivars in terms of productivity potential and seed element concentrations (Tables 4–7), which was consistent with some reports. For example, significant differences were reported among wheat cultivars in terms of plant height, spike length, biological and seed yield (Ram *et al.*, 2016; Sharifi-soltani *et al.*, 2016; Sher *et al.*, 2022), and seed zinc and iron content (Sharifi-soltani *et al.*, 2016; Afzal *et al.*, 2017; Sher *et al.*, 2022).

Meteorological data showed that there were differences in air temperature and rainfall in the two years of the experiment (Fig. 1).The lower rainfall and higher average temperature in the second year compared to the first year caused a decrease in plant height, leaf area, CCI, seed element content, spike length and yield components (Tables 4 and 6). Also, the reduction in HI in the second year compared to the first year (Table 6) indicates a deeper effect of adverse environmental factors on seed yield compared to biological yield. The negative effect of adverse environmental conditions such as decrease in soil moisture and rainfall on leaf characteristics such as area, dimension and number, chlorophyll content, plant height, yield components, seed yield and HI has been reported (Fahad *et al.*, 2017; Ramazan

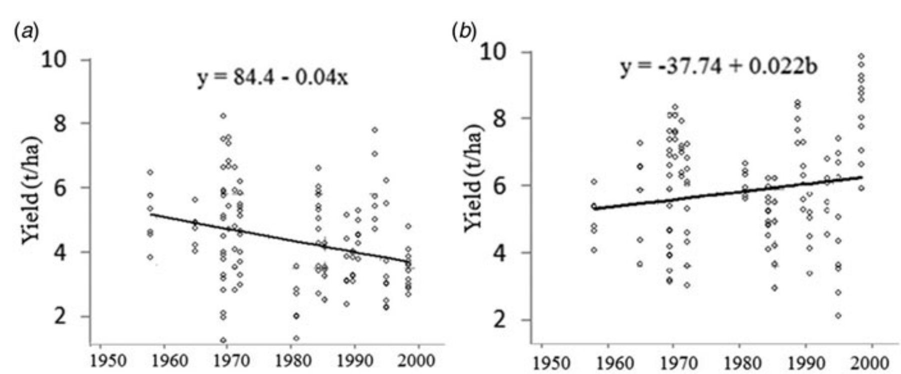

Figure 2. Relationship between seed yield production of 21 wheat cultivars and year of cultivar release from 1960 to 2006 in the conditions without (a) and with (b) zinc sulphate application.

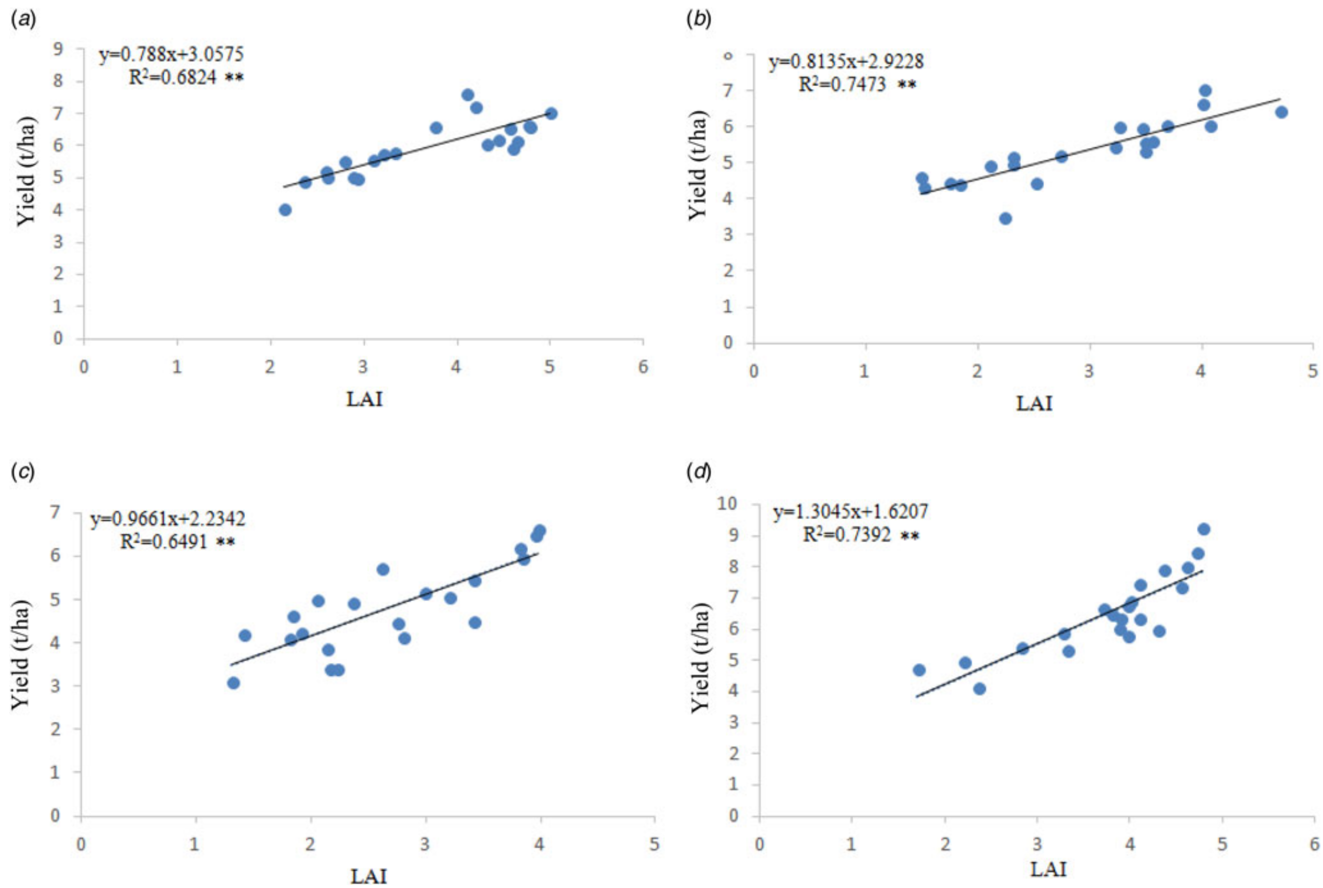

Figure 3. Relation between seed yield and LAI at the flowering stage of 21 wheat cultivars under non-application of zinc sulphate in 2018 (a) and 2019 (b); and with application of zinc sulphate in 2018 (c) and 2019 (d).

et al., 2020; Anwar *et al.*, 2021; Mannan *et al.*, 2022). It seems that during the second year, warmer and drier conditions induced heat and drought stress in the plants. Also, seed quality was affected by adverse conditions in the second year and seed elemental content was reduced compared to the first year (Table 7). An increase in air temperature with a decrease in soil moisture content in spring and in the pre-anthesis stage of wheat can cause a decrease in genetic expression to produce more seeds per unit area and a decrease in seed yield (del Pozo *et al.*, 2016). Heat and drought stress have been reported to decrease the uptake of minerals from the soil and disrupt plant functions (Giri *et al.*, 2017). Fahad *et al.* (2017) also stated that drought and heat stress affect the cycling, absorption, and availability of nutrients to plants. As shown in Fig. 1, after anthesis in the second year, the temperature increased sharply and perhaps there was not enough opportunity for remobilization of elements from the secondary source organs to the seeds. This may explain the decrease in the concentration of elements in the second year compared to the first year.

Zinc application can affect plant functions and performance. For example, zinc application in rice and wheat increased chlorophyll and carotenoid content, improved the activity of phosphoenolpyruvate carboxylase and ribulose bisphosphate carboxylase enzymes, and increased the efficiency of macronutrient use (Anwar *et al.*, 2021; Elshayb *et al.*, 2021). Zinc sulphate application (foliar and soil) also increased the number and area of leaves and CCI in wheat (Ma *et al.*, 2017; Mannan *et al.*, 2022). The increase in leaf area may be due to the effect of zinc element on auxin biosynthesis, cell division and elongation, and the increase in meristem activity (Taiz and Zeiger, 2003). The results of the present research on the increase in CCI, LAI and FLA of wheat cultivars with zinc application were in accordance with the results of the above studies. The linear relationship between LAI and seed yield (Figs 3(a)–(d)) shows that more increase in seed yield is possible by selecting for higher LAI. On the other hand, zinc has an indirect effect on chlorophyll content, so it can have a positive effect on iron uptake, which is necessary for chlorophyll biosynthesis, and increase the chlorophyll content (Anwar *et al.*, 2021). Also, it can be due to the positive role of zinc in chlorophyll synthesis and the enhancement of photosynthesis, which increases the CO_2 assimilation and, increases the protein and carbohydrate production, and finally, leaf area enlargement and plant growth (Sharma *et al.*, 2013; Anwar *et al.*, 2021).

Zinc is an essential element and plays many roles in plant functions such as height increment, biomass accumulation, fertilization and pollen viability (Taiz and Zeiger, 2003). The increase in spike length of wheat with soil and foliar application of zinc (Mannan *et al.*, 2022) and height of rice with application of different sources of zinc (Elshayb *et al.*, 2021) have been reported. Zinc also significantly increased the number of spikelets per spike, number of seeds per spike, and 1000 seed weight in different wheat cultivars (Afzal *et al.*, 2017; Anwar *et al.*, 2021; Mannan *et al.*, 2022). The results of our study regarding the positive effect of zinc on plant height and yield components were consistent with the above reports. There was a direct and positive relationship between the number of spikelets per spike and the number of seeds per spike. Thus, the number of seeds per spike increased with the increase in the number of spikelets per spike. Similarly, zinc can increase seed formation and the number of seeds through the effects on pollination and fertilization and also by increasing the number of spikelets per spike (Taiz and Zeiger, 2003; Panday *et al*., 2006; Afzal *et al*., 2017). Elshayb *et al*. (2021) stated that the increase in seed number and 1000 seed weight in rice may be related to the role of zinc in improving chlorophyll content and enzyme activity, which stimulate photosynthetic rate and photoassimilate translocation to seeds. In addition, zinc affects the uptake of other elements and enhances the remobilization of photoassmilates from the secondary sources to the sink (Elshayb *et al*., 2021; Mannan *et al*., 2022). Environmental stresses such as high temperature can occur and damage wheat plants during growth stages such as reproductive and seed filling stages (Li *et al*., 2016). Zinc application by increasing heat tolerance can protect the photosynthetic system and improve crop yield under heat and moisture deficit conditions and may affect seed growth (Chattha *et al*., 2017; Anwar *et al*., 2021).

The effects of zinc application on crop yield have been reported previously. For example, Sharifi-soltani *et al*. (2016) reported that the application of zinc increased the seed yield of wheat genotypes by 16%. Maleki *et al*. (2014) and Ramazan *et al*. (2020) observed a significant increase in HI of maize and wheat with zinc sulphate application. Our results regarding the increase in biological yield, seed yield, and HI with zinc application were consistent with the results of the above studies. Since zinc is an important component of many enzymes and can increase chlorophyll content and photosynthetic rate, it can affect growth and seed yield (Sharma *et al*., 2013; Anwar *et al*., 2021; Elshayb *et al*., 2021).

In our research, zinc sulphate application affected all measured seed element contents. Jaksomsak *et al*. (2018) found that zinc application increased zinc content in seeds of rice cultivars. Our study showed that in some cultivars, zinc content increased with zinc application. Sharifi-soltani *et al*. (2016) reported the effects of zinc application on wheat genotypes and concluded that the amount of zinc in seeds increased by 18% compared to no zinc application. They stated that zinc application decreased the zinc content of seeds in one cultivar, while it increased it in other cultivars. They also stated that seed iron content was increased by zinc treatment in most cultivars, but decreased in one cultivar (Sharifi-soltani *et al*., 2016). Similarly, Sher *et al*. (2022) stated that the response of wheat cultivars to zinc application can be highly variable, indicating genetic differences in the uptake potential of the elements. For example, one of the cultivars studied had the highest amount of zinc in the seed under zinc application and non-application conditions. The effect of the zinc fertilization on the efficiency of the fertilizer and increasing the zinc concentration of the seeds depends on the cultivar, the type of used fertilizer, and the fertilization time can be different (Hidoto *et al*., 2017). It has been observed that if the application of zinc is done in the final or near to final growth stages of wheat, its effect on zinc concentration of seeds will be greater. On the contrary, fertilization in the early stages of plant life will be effective on growth and yield rather than seed quality (Mutambu *et al*., 2023). However, there are no similar results from different researches (Cakmak, 2008).

In the present study, zinc application showed a decremental effect on phosphorus content of wheat seeds in some cultivars such as Pishtaz, Bayat and Toos (Table 6). This finding may indicate a negative correlation between zinc and phosphorus uptake, which is known by the antagonistic effect of zinc and phosphorus (Bostick *et al*., 2001). Our results also indicated that zinc plays a role in the accumulation of the high concentration of potassium in wheat seeds. It has been noted that zinc application can also affect macroelement uptake and lead to an increase in nutrient use efficiency of macro- and microelements (Sher *et al*., 2022). In wheat, foliar application of zinc increased potassium, zinc and iron contents in shoots and seeds. As the concentration of zinc in the shoot increased, the remobilization and accumulation of zinc in the seed also increased (Anwar *et al*., 2021). In rice, zinc application increased the amount of nitrogen, potassium, and zinc in seeds and decreased the amount of phosphorus in seeds (Elshayb *et al*., 2021). Adequate zinc nutrition has been shown to be important in controlling potassium and iron accumulation by leaves and seeds (Anwar *et al*., 2021). This increase in potassium with zinc application may be due to the synergistic relationship between zinc and potassium, resulting in greater availability of potassium and an increase in potassium flux from the root and shoot to the seed (Elshayb *et al*., 2021). A positive relationship between seed zinc and iron concentrations in cereals has been reported (Xia *et al*., 2019; Anwar *et al*., 2021). The accumulation of zinc and iron in seeds may be due to pleiotropic effects or linkage between genes responsible for zinc and iron accumulation in seeds (Xia *et al*., 2019).

Under non-application of zinc sulphate, the highest seed yield (8.3 t/ha) was obtained in cultivars introduced from 1971 to 1976 years, indicating the high potential yield of old cultivars in soils with lower available zinc and/or without applying zinc sulphate (Fig. 2(a)). On the other hand, with the application of zinc sulphate, the highest seed yield (10.1 t/ha) was observed in the cultivars introduced in the last years, which indicates the positive response and high yield of the newer cultivars with the application of zinc sulphate and the dependence of the newer cultivars on more fertilizers (Fig. 2(b)). It seems that the performance of newer cultivars is more sensitive to conditions that reduce leaf area and photosynthesis rate than older cultivars. This difference explains the yield gap between new and old cultivars in fertile and less fertile environments. del Pozo *et al*. (2022) by studying the regression analysis of seed yield in 25 wheat cultivars and advanced lines introduced from 1959 to 2017 years determined that the increment amount of seed yield between these years was equal to 128.8 kg/ha per year. In another study, durum wheat seed yield showed a positive and linear relationship with the year of cultivar introduction between 1964 and 2010 (del Pozo *et al*., 2019). Senapati and Semenov (2019) also reported an increase in wheat yield from 3.8 mg ha^{-1} in the 1980s to 5.7 mg ha^{-1} after 2010. In Mexico, the seed yield improvement for spring bread wheat cultivars was found to be 30 kg/ha per year (0.59%) from 1966 to 2019 (Aisawi *et al*., 2015). However, in our study, there was a positive and linear relationship between seed yield and release year of wheat cultivar only in the conditions of zinc sulphate application, and in contrast, a negative and linear relationship between seed yield and release year of cultivar was observed in the conditions without zinc sulphate application. It seems that the breeding of new cultivars was done in research stations that had regular annual fertilization and soils with suitable fertility. Therefore, newer cultivars are highly dependent on the application of fertilizers such as zinc sulphate to increase seed yield.

Conclusion

Our results showed that zinc sulphate improved growth, seed yield and yield components. Cultivars had significant differences in response to zinc sulphate. In non-application of zinc sulphate, Moghan2 and Moghan1 cultivars had the highest seed yield, while in application of zinc sulphate, Sirvan, Alamoot and Moghan2 can be introduced as high yielding cultivars. Among the cultivars in both years and under application or non-application of zinc sulphate, Moghan2 showed priority over the other cultivars. In terms of seed quality and nutritional value, Karaj2 had higher elemental concentrations under zinc sulphate application than others. Our data show that zinc sulphate application not only affects seed yield and quality, but also reduces the effect of environmental stress in hot and dry years. The results showed that high-yielding varieties had higher LAI values at flowering. It appears that maintaining greenness at the flowering stage can increase seed yield in wheat cultivars.

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