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ORIGINAL PAPER

Evaluation of macro- and micronutrient responses in confectionery sunflower (*Helianthus annuus* L.) seeds to different fertilizer applications*

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Abstract

This two-year field study, conducted in Kahramanmaraş, Türkiye, in 2021-2022, used a Randomized Complete Block Design (RCBD) with three replications to investigate the effects of 12 different fertilizer applications on the macro- (g kg^{-1}) and micronutrient (mg kg^{-1}) content of confectionery sunflower (*Helianthus annuus* L.) seeds. Significant year × fertilizer application interaction effects were detected for most analyzed nutrients, indicating that treatment responses varied between growing seasons. Different fertilizer applications – chemical, organic, and organomineral – had a clear influence on both macro- and microelement levels in sunflower seeds. The highest increases in grain P (4.036 g kg^{-1}), Ca (2.092 g kg^{-1}), and Mn (4.771 mg kg^{-1}) were obtained with cattle manure applied at 10 000 kg ha^{-1} (CM1). This treatment also resulted in noticeable improvements in N (1.79 g kg^{-1}), Mg (2.224 g kg^{-1}), and Mo (0.118 mg kg^{-1}). When cattle manure (1000 kg ha^{-1}) was combined with chemical fertilizer (90 kg ha^{-1} N and 50 kg ha^{-1} P) as an organomineral treatment (CMCF), the seeds showed the highest N (1.87 g kg^{-1}) and P (4.035 g kg^{-1}) levels, along with marked increases in Mn (4.249 mg kg^{-1}), Zn (54.620 mg kg^{-1}), and Cu (7.424 mg kg^{-1}). The highest Fe content (52.10 mg kg^{-1}) was recorded with gyttja at 20000 kg ha^{-1} (G2), and the highest Mg content (2.332 g kg^{-1}) was determined with gyttja at 80 000 kg ha^{-1} (G3). In comparison, chemical fertilizer alone led to lower P, Ca, Mg, Zn, and Na contents than the control and organic or organomineral applications. These results highlight how different fertilizer types can distinctly shape the nutrient profile of sunflower seeds, offering useful insights for refining fertilization practices in confectionery sunflower production.

Keywords: cattle manure, gyttja, seed macro- and micro-element content, vermicompost

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INTRODUCTION

Sunflower (*Helianthus annuus* L.), a member of the Asteraceae family within the Asterales order, is a globally significant oilseed crop cultivated for both oil extraction and direct consumption as confectionery. The seeds are rich in essential nutrients, including proteins, lipids, and minerals, contributing to their widespread use in human nutrition and livestock feed. Sunflower oil, primarily composed of polyunsaturated fatty acids, is a staple in cooking and food processing industries due to its favorable nutritional profile and stability. Sunflower meal, a by-product of oil extraction, serves as a valuable protein source in animal diets, thereby enhancing the sustainability of sunflower production systems (Petraru et al. 2021, Puraikalan, Scott 2023).

In addition to their nutritional value, sunflower seeds are rich in essential minerals such as potassium, magnesium, phosphorus, and trace elements like iron, zinc, and selenium. These micronutrients play crucial roles in various physiological functions and contribute to the overall health benefits associated with sunflower seed consumption. For instance, sunflower seeds are an excellent source of vitamin E, an antioxidant that protects cells from oxidative damage and supports immune function (Adeleke, Babalola 2020).

Fertilization practices are critical in enhancing soil fertility and optimizing crop yields. The application of fertilizers has been shown to increase agricultural productivity by replenishing essential nutrients in the soil, thereby supporting sustainable crop production systems. However, the use of fertilizers must be managed carefully to avoid negative environmental impacts such as nutrient leaching and soil degradation. Fertilizers are generally categorized into chemical and organic types. Chemical fertilizers provide readily available nutrients, leading to immediate improvements in plant growth and yield. Organic fertilizers, derived from natural sources, contribute to soil health by enhancing microbial activity and improving soil structure. Previous studies have demonstrated that the application of different organic and inorganic fertilizer sources significantly alters the macro- and micronutrient accumulation in various field crops (Doğan et al. 2019). The integration of both types, known as organomineral fertilization, aims to combine the benefits of immediate nutrient availability with long-term soil fertility enhancement. Studies have indicated that organomineral fertilizers can improve nutrient uptake efficiency and increase crop yields compared to the use of chemical fertilizers alone (Alzamel et al. 2022, Silva et al. 2023).

In Türkiye, sunflower cultivation has been expanding due to the increasing demand for edible oils and confectionery products. According to the Turkish Statistical Institute (TurkStat), in 2024, approximately 854,924 ha were planted with oilseed sunflower, yielding 2,180 kg ha^{-1}, and 118,799 ha with confectionery sunflower, yielding 2,870 kg ha^{-1}. This resulted in a total

production of 1,855,000 t of oilseed sunflower and 340,000 t of confectionery sunflower in 2025. These figures underscore the importance of optimizing agronomic practices to enhance both yield and quality in sunflower production.

Recent studies have highlighted the positive effects of organic and organomineral fertilizers on seed germination, root development, and seedling growth in various crops, including sunflower. Kaya and Erdönmez (2020) reported that organic fertilizers improved seedling vigor and nutrient uptake in sunflower. Similarly, research by Kaya et al. (2024*a*) and Kaya et al. (2024*b*) demonstrated that organomineral fertilizers enhanced sunflower seedling establishment and growth parameters. These findings indicate that the use of organic and organomineral fertilizers may contribute to sustainable sunflower production systems by improving early plant development and overall crop performance.

The nutrient composition of sunflower seeds is influenced by various factors, including fertilization practices. Studies have shown that the application of organomineral fertilizers can increase the concentrations of essential macro- and micronutrients in sunflower seeds, thereby enhancing their nutritional value. For instance, research by Alzamel et al. (2022) indicated that organomineral fertilization improved the levels of nitrogen, phosphorus, and potassium in sunflower seeds. Similarly, Silva et al. (2023) reported that the use of organic and mineral fertilization influenced the nutrient content and quality parameters of sunflower seeds.

Therefore, this study was conducted to evaluate the effects of chemical, organic, and organomineral fertilizer applications on the main macro- and micronutrient contents in the grains of confectionery sunflower (*Helianthus annuus* L.) under the environmental conditions of Kahramanmaraş, Türkiye. The specific objective was to determine how different fertilization strategies influence the concentrations of key essential nutrients – specifically nitrogen, phosphorus, potassium, magnesium, calcium, zinc, manganese, and iron – in sunflower seeds. The findings aim to provide insights into optimizing fertilization practices to enhance both the yield and nutritional quality of sunflower seeds in the region.

MATERIALS AND METHODS

Experimental design and site description

This two-year field experiment (2021-2022) was conducted at the experimental field of the Department of Field Crops, Faculty of Agriculture, Kahramanmaraş Sütçü İmam University, Türkiye. The experimental design followed a Randomized Complete Block Design (RCBD) with three replications. Each plot measured 0.70 m × 5.00 m and consisted of four rows (14 m² in total), with 12 plots per block and 3.00 m spacing between blocks. Seeds

of the İnegöl Alası cultivar were obtained from farmers affiliated with the Elbistan Chamber of Agriculture. The soil was plowed deeply in autumn, followed by shallow cultivation in early spring to prepare a uniform seedbed. Sowing was performed manually on April 9, 2021, and April 7, 2022, using four-row plots (0.70 m × 5.00 m). Emergence irrigation was applied immediately after sowing. Subsequent irrigations were conducted via a drip irrigation system. The system consisted of 16 mm diameter polyethylene drip lines with inline emitters spaced at 30 cm intervals, each delivering a flow rate of 2.2 L h^{-1} at an operating pressure of 1.0 bar. One drip line was placed along each crop row at a distance of 10 cm from the plant stems. Irrigation was scheduled at 7-day intervals. No fungicides or insecticides were applied during the growing seasons. Weed control was performed manually three times per season. No significant pest or disease pressure was observed in either year and harvest was carried out manually at physiological maturity in mid-August of both years.

Plant material

The experimental material consisted of the *İnegöl Alası* sunflower cultivar, a confectionery-type variety officially registered by the İnegöl Municipality in 2013. The seeds were obtained from local farmers affiliated with the Elbistan Chamber of Agriculture. This cultivar is known for its large seeds, high nutritional content, and adaptability to the regional growing conditions of southeastern Türkiye.

Soil characteristics and climatic conditions

Prior to the experiment, composite soil samples (0-30 cm depth) were collected and analyzed at the ÜSKİM Soil Analysis Laboratory of Kahramanmaraş Sütçü İmam University. The soils were slightly alkaline (pH 7.58), with low lime content (9.3 g kg^{-1}) and moderate organic matter (11.6 g kg^{-1}). They exhibited a clay-loam texture, low salinity (1.0 g kg^{-1}), and adequate phosphorus levels (4.73 ppm), indicating moderate fertility suitable for sunflower cultivation. Kahramanmaraş has a typical Mediterranean climate characterized by hot, dry summers and mild, wet winters. Meteorological data from 2021-2022 (Provincial Directorate of Meteorology) indicated higher mean temperatures and lower precipitation compared to long-term averages (1930-2021). Total rainfall during the April–August growth period was 32.3 mm in 2021 and 42.6 mm in 2022, considerably below the long-term mean of 125.3 mm, indicating relatively dry conditions that challenged water availability for sunflower growth (Figure 1).

Fertilizer properties

The nutrient composition data presented in Table 1 for organic fertilizers (vermicompost, cattle manure, and gyttja) were provided by the supplying companies as declared values based on their internal quality control analyses. The chemical fertilizer composition was obtained from the manufacturer's

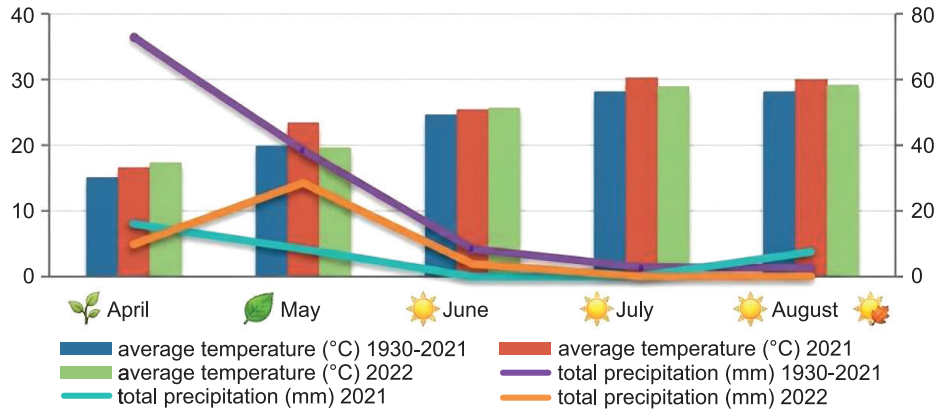


Fig. 1. Climate data of the vegetation period (April–August) for 2021-2022 and long-term (1930-2021)

product specification sheet. While these values represent the stated composition at the time of procurement, it is acknowledged that inherent variability may exist in organic materials. Therefore, the results of this study were interpreted with consideration of these declared values as reference points rather than absolute measurements.

Fertilizer applications

Twelve fertilizer applications were carried out, including a control (no fertilizer), a chemical fertilizer (90 kg N + 50 kg P ha^{-1}), three organic fertilizers (gyttja, vermicompost, and cattle manure), and their respective organomineral combinations with the chemical fertilizer dose. The experimental layout and fertilizer applications are summarized in Table 2.

For chemical fertilizer treatments, 50 kg N + 50 kg P ha^{-1} was applied during sowing as a basal dose. The remaining nitrogen (40 kg N ha^{-1}) was applied as ammonium sulfate (21% N) as a top-dressing treatment when plants reached approximately 30 cm in height. All chemical fertilizers were incorporated into the top 5-10 cm of soil using a hand rake immediately after application to minimize ammonia volatilization.

Organic fertilizers (gyttja, vermicompost, and cattle manure) were applied one week before sowing. They were uniformly hand-broadcast over each plot and thoroughly incorporated into the soil to a depth of approximately 15-20 cm using a rotary tiller to ensure homogeneous mixing and to initiate microbial decomposition prior to sowing.

In organomineral treatments (GCF, VCF, CMCF), the organic component (1000 kg ha^{-1}) was applied and incorporated one week before sowing as described above. The chemical fertilizer component (90 kg N + 50 kg P ha^{-1}) was then applied at sowing time, with half (50 kg N + 50 kg P) incorporated into the seedbed and the remaining nitrogen (40 kg N) applied as top-dressing at the 30-cm growth stage.

Table 1

Nutrient composition of fertilizers used in the experiment

Fertilizer type	Organic matter (g kg^{-1})	Total N (g kg^{-1})	P (g kg^{-1})	K (g kg^{-1})	Ca (g kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Humic + fulvic acid (g kg^{-1})	pH range	Remarks
Vermicompost	350.0	13.0	15.0	12.0	–	–	–	200.0	6.0-8.0	balanced organic source rich in microbial biomass
Cattle manure	600.0	28.0	24.0	25.0	–	–	–	310.0	6.5-8.5	high nutrient content; improves soil structure and aeration
Gyttja	430.0	11.3	3.0	0.14	10.28	0.0011	0.00022	340.0	7.1	rich in humic substances; enhances cation exchange capacity
Chemical fertilizer (20.20.0 + ammonium sulfate (21% N))	–	205.0	170.	–	–	–	–	–	6.8	provides immediately available N and P nutrients

Table 2

Fertilizer applications and treatment rates

Treatment Code	Description
Control	no fertilizer
CF	90 kg ha^{-1} N + 50 kg ha^{-1} P
G1, G2, G3	gyttja at 10 000, 20 000, and 80 000 kg ha^{-1}
V1, V2	vermicompost at 10 000 and 20 000 kg ha^{-1}
CM1, CM2	cattle manure at 10 000 and 20 000 kg ha^{-1}
GCF, VCF, CMCF	gyttja, vermicompost, or cattle manure (1000 kg ha^{-1}) + CF dose

Nutrient analysis

At harvest, seed samples were collected from each experimental plot. Approximately 5 g of seeds from each sample were finely ground and analyzed for macronutrients – nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca) – as well as micronutrients including iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), and sodium (Na). All analyses were performed at the ÜSKİM Laboratories of Kahramanmaraş Sütçü İmam University following standard analytical protocols: total nitrogen was determined using the Kjeldahl method, phosphorus by spectrophotometric analysis, and the remaining elements (K, Ca, Mg, Fe, Mn, Zn, Cu, Mo, and Na) by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

Statistical analysis

All data were analyzed using SAS 9.0 statistical software (SAS Institute Inc., Cary, NC, USA) according to the Randomized Complete Block Design (RCBD). Because the experiment was conducted over two growing seasons, year was treated as a fixed effect and the Year × Fertilizer Application interaction was included in the model (Littell et al. 2006). Analysis of variance (ANOVA) was performed to test the effects of year, fertilizer application, and their interaction. Mean comparisons were performed using Tukey's honestly significant difference (HSD) test at $p \leq 0.05$ as the conservative post-hoc procedure. Where the Year × Fertilizer Application interaction was significant, treatment means were interpreted within year. Coefficients of variation (CV) were calculated to describe experimental precision.

RESULTS AND DISCUSSION

Macronutrient contents in sunflower seeds

The effects of different fertilizer applications on the macronutrient composition (Ca, K, Mg, N, and P) of confectionery sunflower seeds were statistically significant at both the 5% and 1% probability levels (Table 3). As shown

Table 3

Analysis of variance for macronutrient (Ca, K, Mg, N, and P) concentrations in confectionery sunflower seeds as affected by year (Y), fertilizer application (FA), and their interaction (Y × FA)

Trait	Source of variation	df	MS	F	P	Sig.
Ca (g kg^{-1})	block	2	0.02014170	14.689376	0.0000	**
	year (Y)	1	0.00065401	0.4769739	0.4933	ns
	fertilizer (FA)	11	0.10900400	79.496912	0.0000	**
	Y × FA	11	0.04938760	36.018488	0.0000	**
	error	46	0.00137120			
	total	71				
K (g kg^{-1})	block	2	0.13531330	22.589202	0.0000	**
	year (Y)	1	94.45564000	15768.426	0.0000	**
	fertilizer (FA)	11	0.39149980	65.356979	0.0000	**
	Y × FA	11	0.43518660	72.650052	0.0000	**
	error	46	0.00599020			
	total	71				
Mg (g kg^{-1})	block	2	0.03309820	17.847070	0.0000	**
	year (Y)	1	8.17629400	4408.790700	0.0000	**
	fertilizer (FA)	11	0.11314370	61.008907	0.0000	**
	Y × FA	11	0.11045660	59.559973	0.0000	**
	error	46	0.00185450			
	total	71				
N (g kg^{-1})	block	2	0.00850420	2.2985360	0.1118	ns
	year (Y)	1	0.00586810	1.5860386	0.2142	ns
	fertilizer (FA)	11	0.01047010	2.8298888	0.0066	*
	Y × FA	11	0.02097710	5.6697766	0.0000	**
	error	46	0.00369980			
	total	71				
P (g kg^{-1})	block	2	0.24219870	20.1367800	0.0000	**
	year (Y)	1	0.10966810	9.1179735	0.0041	*
	fertilizer (FA)	11	0.70817760	58.8789960	0.0000	**
	Y × FA	11	1.02727680	85.4093990	0.0000	**
	error	46	0.01202770			
	total	71				

df – degrees of freedom, MS – mean square, F – F value, ns – not significant, * significant at $p<0.05$, ** significant at $p<0.01$

in Table 3, significant year × fertilizer application interactions were detected for K, Mg, P, and N, indicating that fertilizer responses were not consistent between the two growing seasons. The year effect itself was highly significant for Mg, P, K, reflecting the pronounced influence of the contrasting

climatic conditions between 2021 and 2022 on soil nutrient dynamics. The results indicated that the use of organic and organomineral fertilizers, particularly those based on cattle manure and gyttja, substantially enhanced the accumulation of macro elements compared with the control and chemical fertilizer applications.

Calcium (Ca)

Calcium concentration ranged between 1.45 and 2.09 g kg^{-1}, with significant differences among fertilizer applications. The highest Ca level was obtained in CM1 (2.09 g kg^{-1}), while the lowest occurred in CF (1.60 g kg^{-1}) – Table 4 and Figure 2*a*. Although the year effect for Ca was not significant, the Y × FA interaction was highly significant ($p<0.01$), indicating treatment-dependent seasonal variation (Table 3). In Y1, CM1 reached the highest Ca (2.208 g kg^{-1}); in Y2, CM1 remained among the highest (1.977 g kg^{-1}), supporting the consistency of cattle manure in enhancing Ca uptake across both seasons (Table 4). These results align with Niyazaliev et al. (2023), who found that manure-based amendments enhance Ca uptake by improving cation exchange capacity and soil aeration. Enhanced Ca levels in the CM1 treatment indicate that moderate doses of organic amendments are particularly effective in maintaining soil balance and improving nutrient assimilation (Thomas et al. 2019).

Potassium (K)

The mean K content varied between 5.37 and 7.64 g kg^{-1}, showing significant differences ($p<0.01$) among treatments. As shown in Tables 3 and 4, the year effect was significant ($p<0.01$), with Y2 recording slightly higher K means (6.618 g kg^{-1}) than Y1 (6.540 g kg^{-1}). The G1 (gyttja 10 000 kg ha^{-1}) treatment led to the highest K concentration (7.08 g kg^{-1}), whereas the lowest was found in V2 (5.80 g kg^{-1}). Interestingly, the control plots in 2021 also exhibited high potassium levels, suggesting sufficient native K reserves in the soil. The highly significant Y × FA interaction ($p<0.01$) indicated strongly divergent treatment responses between years (Table 3). In Y1, the control provided the highest K (7.639 g kg^{-1}), suggesting sufficient native soil K reserves under drier conditions. In Y2, CMCF achieved the highest K (7.121 g kg^{-1}), emphasizing the synergistic effect of combining organic and mineral sources under favorable moisture conditions (Table 4 and Figure 2*a*). Similar findings were observed by Kandil et al. (2020), who reported that natural soil K reserves can sustain crop requirements under favorable climatic conditions. The enhanced K levels in the organomineral treatments, particularly CMCF, emphasize the synergistic effect of combining organic and mineral sources, which improves root uptake and K retention in the soil. The K element content in the grain was found to be higher in the VCF application than in the CF application, aligning with observations that biofertilizers containing beneficial microorganisms can enhance potassium availabili-

Table 4

Mean macronutrient (Ca, K, Mg, N, and P) concentrations in confectionery sunflower seeds under different fertilizer applications and their corresponding Tukey (HSD) groupings

Treatments		Ca (g kg^{-1})		K (g kg^{-1})		Mg (g kg^{-1})		N (g kg^{-1})		P (g kg^{-1})	
Years (Y)	Y1	1.816		6.540	*b*	1.751	*b*	18.17		2.522	*b*
	Y2	1.822		6.618	*a*	2.425	*a*	18.00		4.812	*a*
Fertilizer applications (FA)	control	1.868	*cd*	6.911	*ab*	2.178	*b*	17.35	*b*	3.609	*de*
	CF	1.602	*h*	6.266	*e*	1.853	*e*	17.95	*ab*	3.180	*g*
	G1	1.940	*bc*	7.079	*a*	2.217	*b*	18.30	*ab*	3.711	*cd*
	G2	1.734	*fg*	6.623	*c*	2.037	*c*	18.21	*ab*	3.562	*de*
	G3	1.962	*b*	6.889	*ab*	2.332	*a*	18.21	*ab*	3.905	*ab*
	V1	1.812	*de*	6.350	*de*	2.010	*cd*	17.34	*b*	3.573	*de*
	V2	1.768	*ef*	5.799	*f*	1.995	*cd*	18.03	*ab*	3.396	*f*
	CM1	2.092	*a*	6.736	*bc*	2.224	*b*	17.85	*ab*	4.036	*a*
	CM2	1.678	*g*	6.698	*bc*	2.066	*c*	18.25	*ab*	3.853	*bc*
	GCF	1.716	*fg*	6.567	*cd*	1.936	*de*	18.49	*ab*	3.607	*de*
	VCF	1.815	*de*	6.384	*de*	2.039	*c*	18.35	*ab*	3.538	*ef*
	CMCF	1.836	*de*	6.644	*c*	2.166	*b*	18.70	*a*	4.035	*a*
Average	1.819		6.579		2.088		18.09		3.667		
Year x fertilizer applications (Y x FA)	Y1 x control	1.939	*bcde*	7.639	*a*	2.083	*f*	18.30	*abcd*	2.925	*g*
	Y1 x CF	1.453	*l*	6.372	*hi*	1.410	*k*	18.25	*abcd*	1.924	*l*
	Y1 x G1	2.030	*b*	7.430	*ab*	2.097	*f*	17.36	*abcd*	3.017	*g*
	Y1 x G2	1.763	*ghijk*	6.842	*cdef*	1.800	*gh*	17.31	*bcd*	2.379	*ijk*
	Y1 x G3	2.028	*b*	6.946	*cde*	2.054	*f*	18.82	*abc*	2.548	*hij*
	Y1 x V1	1.667	*jk*	5.828	*jk*	1.498	*jk*	17.73	*abcd*	2.249	*k*
	Y1 x V2	1.708	*ijk*	5.369	*l*	1.649	*i*	18.35	*abc*	2.143	*kl*
	Y1 x CM1	2.208	*a*	7.034	*cd*	1.870	*g*	18.14	*abcd*	2.661	*h*
	Y1 x CM2	1.651	*k*	6.402	*ghi*	1.653	*i*	18.56	*abc*	2.329	*jk*

cont. Table 4

Year x fertilizer applications (Y x FA)	Y1 x GCF	1.774	*ghij*	6.632	*efgh*	1.620	*ij*	18.72	*abc*	2.616	*hi*
	Y1 x VCF	1.726	*hijk*	5.819	*k*	1.605	*ij*	17.73	*abcd*	2.342	*jk*
	Y1 x CMCF	1.839	*efgh*	6.167	*ij*	1.670	*hi*	18.82	*abc*	3.127	*g*
	Y2 x control	1.797	*fghi*	6.184	*i*	2.272	*e*	16.40	*d*	4.293	*f*
	Y2 x CF	1.752	*ghijk*	6.160	*ijk*	2.297	*e*	17.64	*abcd*	4.436	*def*
	Y2 x G1	1.850	*defg*	6.728	*defg*	2.338	*de*	19.24	*a*	4.405	*ef*
	Y2 x G2	1.704	*ijk*	6.405	*ghi*	2.274	*e*	19.11	*ab*	4.745	*bc*
	Y2 x G3	1.895	*cdef*	6.832	*cdef*	2.609	*ab*	17.60	*abcd*	5.261	*a*
	Y2 x V1	1.957	*bcd*	6.873	*cde*	2.523	*bc*	16.96	*cd*	4.897	*b*
	Y2 x V2	1.827	*efgh*	6.229	*i*	2.340	*de*	17.71	*abcd*	4.650	*cd*
	Y2 x CM1	1.977	*bc*	6.438	*ghi*	2.579	*abc*	17.56	*abcd*	5.411	*a*
	Y2 x CM2	1.705	*ijk*	6.995	*cd*	2.479	*bc*	17.95	*abcd*	5.377	*a*
	Y2 x GCF	1.658	*jk*	6.502	*fghi*	2.252	*e*	18.27	*abcd*	4.597	*cde*
	Y2 x VCF	1.904	*cdef*	6.950	*cde*	2.473	*cd*	18.98	*ab*	4.735	*bc*
	Y2 x CMCF	1.834	*efgh*	7.121	*bc*	2.662	*a*	18.57	*abc*	4.943	*b*
Average	1.819		6.579		2.088		18.09		3.667		
HSD (Tukey, 5%) for Y	ns	0.052	*	0.020	*	ns	0.037	*			
HSD (Tukey, 5%) for FA	0.074	*	0.218	*	0.086	*	0.121	*	0.154	*	
HSD (Tukey, 5%) for Y x FA	0.117	*	0.346	*	0.136	*	0.192	*	0.244	*	
CV	2.040		1.670		2.060		3.360		2.110		

CV – coefficient of variation, ns – not significant, FF or FA – fertilizer applications, Y – Year, Y1 – 2021, Y2 – 2022, CF – chemical fertilizer (90 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5), G1 – gyttja 10 000 kg ha^{-1}, G2 – gyttja 20 000 kg ha^{-1}, G3 – gyttja 80 000 kg ha^{-1}, V1 – vermicompost 10 000 kg ha^{-1}, V2 – vermicompost 20 000 kg ha^{-1}, CM1 – cattle manure 10 000 kg ha^{-1}, CM2 – cattle manure 20 000 kg ha^{-1}, GCF – gyttja + chemical fertilizer, VCF – vermicompost + chemical fertilizer, CMCF – cattle manure + chemical fertilizer.

* Means followed by different letters within the same column are significantly different according to the Tukey (HSD) test at the 5% significance level (p<0.05), ns – not statistically significant (p>0.05), blank letter cells indicate that the corresponding factor was not significant (ns) for that variable.

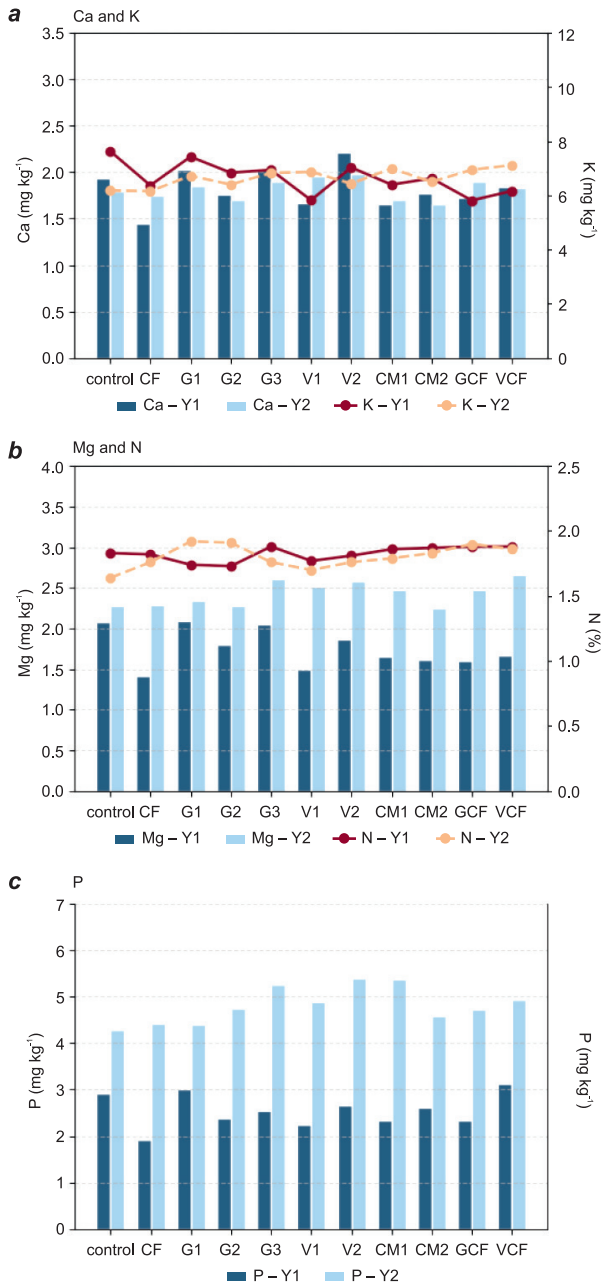


Fig. 2. Effects of different fertilizer applications on seed Ca and K (*a*), Mg and N (*b*), and P (*c*) concentrations across two experimental years

ty and uptake (Ghasemi-Tabasi et al. 2023). The K content in the grain was found to be lower in applications of CM (cattle manure) and V (vermicompost manure) compared to the control application. These findings are consistent with the data reported by Çitak et al. (2011) for applications of 1000 and 2000 kg ha^{-1} vermicompost and 15 000-30 000 kg ha^{-1} farmyard manure in spinach plants. Conversely, the K content in the grain was higher in the CMCF (cattle manure + chemical fertilizer) organomineral fertilizer application than in the chemical fertilizer application alone. These results align with the findings of Alauddin et al. (2022) and Gholamhoseini et al. (2013).

Magnesium (Mg)

Magnesium (Mg) content varied significantly among the treatments, ranging from 1.41 to 2.66 g kg^{-1} (Table 4). The year effect was the most pronounced factor affecting Mg content ($p<0.01$, Table 3), with Y2 exhibiting a significantly higher Mg concentration than Y1 (2.425 vs. 1.751 g kg^{-1}). This pronounced difference likely reflects cumulative organic matter mineralization and improved soil biological activity in the second season. As shown in Table 3, the Y × FA interaction was also highly significant ($p<0.01$), with G3 reaching the highest Mg in Y2 (2.609 g kg^{-1}) and CM1 ranking highest in Y1 (1.870 g kg^{-1}). The G3 (gyttja 80 000 kg ha^{-1}) and CM1 (cattle manure 10 000 kg ha^{-1}) treatments recorded the highest Mg concentrations (2.332 and 2.224 g kg^{-1}, respectively) – Table 4 and Figure 2*b*. The second year (Y2) showed generally higher Mg levels, reflecting cumulative effects of organic matter mineralization (Table 4). Similar trends were reported by Çitak et al. (2011) and Thomas et al. (2019), emphasizing that sustained organic inputs improve Mg bioavailability through enhanced root growth and microbial activity.

Nitrogen (N)

Seed nitrogen content ranged between 1.700 g kg^{-1} and 1.920 g kg^{-1}, showing significant variation among treatments and years. Unlike most other nutrients, the year effect for N was not significant, indicating stable nitrogen accumulation across seasons. However, the significant Y × FA interaction ($p<0.01$) indicated that the magnitude of treatment responses varied across years (Table 3). Despite this year-to-year variation, CMCF consistently resulted in the highest nitrogen content in both years (1.880 g kg^{-1} in Y1 and 1.860 g kg^{-1} in Y2), exceeding the values obtained under all other fertilizer treatments (Table 4). The consistency of this response across years suggests that the organomineral fertilizer combination may provide a stable and effective approach for enhancing nitrogen accumulation under different seasonal conditions. The highest N value was recorded in the CMCF (cattle manure + chemical fertilizer) treatment (1.870 g kg^{-1}), followed closely by G1 (1.830 g kg^{-1}) and G3 (1.820 g kg^{-1}). In contrast, the lowest N values occurred in the vermicompost (V1) and control treatments (Table 4 and Figure 2*b*).

These results suggest that organic amendments, particularly cattle manure, provided sustained release of nitrogen through mineralization, resulting in improved uptake and grain accumulation. Similar findings were reported by Ghasemi-Tabasi et al. (2023) and Koskey et al. (2022), who demonstrated that vermicompost and cattle manure enhance soil microbial activity and nitrogen bioavailability. Furthermore, organomineral combinations (CMCF and VCF) outperformed the chemical fertilizer alone, likely due to improved nutrient synchronization and soil structure (Al-Tawarah et al. 2023).

Phosphorus (P)

Phosphorus concentration in the seeds ranged from 1.92 to 5.41 g kg^{-1} and was significantly influenced by year, fertilizer type, and their interaction. The CMCF and CM1 treatments achieved the highest P values (4.035-4.036 g kg^{-1}), whereas the chemical fertilizer (CF) treatment resulted in the lowest P content (3.180 g kg^{-1}). The year effect was the strongest detected in this study (p<0.01), with Y2 mean (4.812 g kg^{-1}) nearly double that of Y1 (2.522 g kg^{-1}). This large between-year difference is attributed to the wetter 2022 season, which substantially promoted soil P mineralization. Due to the highly significant Y × FA interaction (p < 0.01), treatment comparisons are most meaningful within each year (Tables 3 and 4). In Y1, CMCF induced the highest P (3.127 g kg^{-1}); in Y2, CM1 and CM2 reached the highest values (5.411 and 5.377 g kg^{-1} respectively), while CF remained the lowest in both years (Table 4 and Figure 2*c*). The increase in phosphorus uptake during the second year is attributed to improved soil biological activity and organic matter decomposition that enhanced P solubility and plant availability (Sireesha et al. 2019). These results confirm earlier reports that organic fertilizers, particularly manure-based ones, promote P mobilization by stimulating soil enzymes such as phosphatase (Çitak et al. 2011).

Micronutrient contents in sunflower seeds

Significant differences were also observed in the micronutrient concentrations (Cu, Fe, Mn, Mo, Na, and Zn) across fertilizer applications. All micronutrients showed highly significant Y × FA interactions (F-values: 9.63-178.57, p<0.01, Tables 5 and 6). Year effects were significant for Fe, Mn, and Zn (p<0.01), but not significant for Cu, Mo, and Na (Table 5 and Figure 3). Overall, the incorporation of organic and organomineral fertilizers led to improved micronutrient accumulation, particularly of zinc, manganese, and iron.

Copper (Cu)

Copper concentrations ranged from 5.59 to 9.63 mg kg^{-1}, with the highest values in the control and CMCF treatments. The relatively higher Cu levels in the control suggest that native soil Cu was adequate, while the organic

Table 5

Analysis of variance for macronutrient (Cu, Fe, Mn, Mo, Na and Zn) concentrations in confectionery sunflower seeds as affected by year (Y), fertilizer application (FA), and their interaction (Y × FA).

Trait	Source of variation	df	MS	F	P	Sig.
Cu (mg kg^{-1})	block	2	0.28041350	14.859195	0.0000	**
	year (Y)	1	0.00000001	0.000001	1.0000	ns
	fertilizer (FA)	11	1.46627910	77.698551	0.0000	**
	Y × FA	11	2.63753200	139.763580	0.0000	**
	error	46	0.01887140			
	total	71				
Fe (mg kg^{-1})	block	2	4.4249820	4.1924089	0.0213	*
	year (Y)	1	1844.5523000	1747.6043000	0.0000	**
	fertilizer (FA)	11	159.4344600	151.0547300	0.0000	**
	Y × FA	11	185.9058300	176.1347900	0.0000	**
	error	46	1.0554748			
	total	71				
Mn (mg kg^{-1})	block	2	0.1602190	16.133551	0.0000	**
	year (Y)	1	237.5182800	23917.344000	0.0000	**
	fertilizer (FA)	11	1.8231318	183.583650	0.0000	**
	Y × FA	11	1.7758772	178.825260	0.0000	**
	error	46	0.0099308			
	total	71				
Mo (mg kg^{-1})	block	2	0.00007350	4.7912140	0.0129	*
	year (Y)	1	0.00000001	0.0009054	0.9761	ns
	fertilizer (FA)	11	0.00013431	8.7550028	0.0000	**
	Y × FA	11	0.00014471	9.4332067	0.0000	**
	error	46	0.00001534			
	total	71				
Na (mg kg^{-1})	block	2	7.01005870	9.1261366	0.0005	**
	year (Y)	1	0.00000001	0.0000000	1.0000	ns
	fertilizer (FA)	11	205.02942000	266.9202300	0.0000	**
	Y × FA	11	109.15400000	142.1035600	0.0000	**
	error	46	0.76812990			
	total	71				
Zn (mg kg^{-1})	block	2	32.7246290	20.396003	0.0000	**
	year (Y)	1	52155.5640000	32506.557000	0.0000	**
	fertilizer (FA)	11	87.4351600	54.494972	0.0000	**
	Y × FA	11	41.8726500	26.097612	0.0000	**
	error	46	1.6044629			
	total	71				

df – degrees of freedom, MS – mean square, F – F value, ns – not significant, * significant at $p<0.05$, ** significant at $p<0.01$

Table 6

Mean micronutrient (Cu, Fe, Mn, Mo, Na and Zn) concentrations in confectionery sunflower seeds under different fertilizer applications and their corresponding Tukey (HSD) groupings

Treatments		Cu (mg kg^{-1})		Fe (mg kg^{-1})		Mn (mg kg^{-1})		Mo (mg kg^{-1})		Na (mg kg^{-1})		Zn (mg kg^{-1})	
Years (Y)	Y1	6.975		24.917	*a*	1.777	*b*	0.111		35.505		23.139	*b*
	Y2	6.975		14.794	*b*	5.410	*a*	0.111		35.505		76.967	*a*
Fertilizer applications (FA)	Control	8.028	*a*	19.431	*de*	3.893	*c*	0.114	*abcd*	51.285	*a*	51.199	*cd*
	CF	6.689	*fg*	17.655	*ef*	3.633	*d*	0.106	*e*	28.081	*h*	43.295	*h*
	G1	7.098	*cd*	21.542	*c*	3.658	*d*	0.108	*de*	39.673	*b*	49.128	*def*
	G2	6.057	*h*	32.411	*a*	3.713	*cd*	0.105	*e*	34.221	*de*	47.104	*fg*
	G3	6.542	*g*	20.362	*cd*	3.432	*e*	0.108	*de*	33.662	*ef*	51.919	*c*
	V1	6.693	*fg*	26.393	*b*	3.012	*fg*	0.111	*bcde*	34.617	*de*	49.039	*def*
	V2	6.928	*def*	14.637	*g*	2.830	*g*	0.120	*a*	35.509	*d*	50.049	*cde*
	CM1	6.802	*efg*	16.638	*fg*	4.771	*a*	0.118	*ab*	37.879	*c*	52.436	*bc*
	CM2	7.328	*bc*	20.502	*cd*	3.702	*cd*	0.109	*cde*	35.874	*d*	57.427	*a*
	GCF	7.047	*de*	15.082	*g*	3.108	*f*	0.116	*abc*	31.266	*g*	48.251	*efg*
	VCF	7.062	*cde*	18.294	*ef*	3.122	*f*	0.111	*bcde*	31.699	*g*	46.169	*g*
	CMCF	7.424	*b*	15.320	*g*	4.249	*b*	0.109	*cde*	32.290	*fg*	54.620	*b*
Average		6.975		19.856		3.594		0.111		35.505		50.053	
Year x fertilizer applications (Y x FA)	Y1 x control	6.426	*ef*	19.220	*fg*	2.671	*ij*	0.110	*bcde*	39.283	*bc*	23.230	*ij*
	Y1 x CF	7.810	*b*	20.045	*efg*	2.482	*j*	0.111	*bcde*	26.862	*h*	15.055	*l*
	Y1 x G1	6.822	*de*	25.330	*d*	2.857	*i*	0.109	*bcde*	39.099	*bc*	22.665	*jk*
	Y1 x G2	5.596	*g*	52.100	*a*	1.925	*k*	0.111	*bcde*	37.508	*bc*	21.720	*jk*
	Y1 x G3	6.426	*ef*	30.205	*c*	1.228	*lm*	0.108	*bcde*	37.753	*bc*	26.975	*hi*
	Y1 x V1	7.138	*cd*	35.230	*b*	1.024	*m*	0.113	*bcd*	36.835	*cd*	18.705	*kl*
	Y1 x V2	7.375	*c*	18.125	*fghi*	1.053	*m*	0.113	*bcd*	37.937	*bc*	22.995	*ij*
	Y1 x CM1	6.822	*de*	18.295	*fgh*	2.143	*k*	0.109	*bcde*	38.855	*bc*	22.920	*j*
	Y1 x CM2	7.158	*cd*	22.955	*de*	1.290	*lm*	0.115	*ab*	38.671	*bc*	28.435	*h*
	Y1 x GCF	7.454	*bc*	20.875	*ef*	1.489	*l*	0.114	*bc*	31.145	*fg*	19.975	*jk*

cont. Table 6

Year x fertilizer applications (Y x FA)	Y1 x VCF	7.375	*c*	18.000	*fghi*	1.144	*m*	0.110	*bcde*	29.126	*gh*	20.970	*jk*
	Y1 x CMCF	7.296	*c*	18.625	*fg*	2.022	*k*	0.112	*bcd*	32.981	*ef*	34.020	*g*
	Y2 x control	9.630	*a*	19.642	*fg*	5.115	*e*	0.119	*ab*	63.287	*a*	79.169	*bcd*
	Y2 x CF	5.567	*g*	15.266	*hij*	4.784	*fg*	0.102	*de*	29.300	*gh*	71.536	*f*
	Y2 x G1	7.375	*c*	17.754	*fghi*	4.459	*h*	0.107	*bcde*	40.246	*b*	75.591	*cde*
	Y2 x G2	6.518	*ef*	12.722	*jkl*	5.502	*d*	0.099	*e*	30.934	*fg*	72.487	*ef*
	Y2 x G3	6.657	*ef*	10.518	*lm*	5.636	*d*	0.107	*bcde*	29.570	*gh*	76.864	*cd*
	Y2 x V1	6.247	*f*	17.556	*ghi*	5.001	*ef*	0.108	*bcde*	32.399	*ef*	79.372	*bc*
	Y2 x V2	6.481	*ef*	11.149	*lm*	4.608	*gh*	0.127	*a*	33.081	*ef*	77.103	*cd*
	Y2 x CM1	6.783	*de*	14.981	*ijk*	7.398	*a*	0.127	*a*	36.903	*cd*	81.952	*b*
	Y2 x CM2	7.499	*bc*	18.049	*fghi*	6.114	*c*	0.102	*cde*	33.076	*ef*	86.420	*a*
	Y2 x GCF	6.640	*ef*	9.289	*m*	4.726	*fgh*	0.118	*ab*	31.387	*fg*	76.528	*cd*
	Y2 x VCF	6.749	*de*	18.589	*fg*	5.099	*e*	0.111	*bcde*	34.272	*de*	71.368	*f*
	Y2 x CMCF	7.552	*bc*	12.014	*klm*	6.477	*b*	0.107	*bcde*	31.600	*efg*	75.220	*def*
Average		6.975		19.856		3.594		0.111		35.505		50.053	
HSD (Tukey, 5%) for Y		ns		0.487	*	0.047	*	ns		ns		0.601	*
HSD (Tukey, 5%) for FA		0.273	*	2.041	*	0.198	*	0.008	*	1.741	*	2.516	*
HSD (Tukey, 5%) for Y x FA		0.433	*	3.241	*	0.315	*	0.012	*	2.765	*	3.996	*
CV		1.970		5.170		2.770		3.520		2.470		2.530	

CV – coefficient of variation, ns – none significant, FF or FA – fertilizer applications, Y – Year, Y1 – 2021, Y2 – 2022, CF – chemical fertilizer (90 kg ha^{-1} N and 50 kg ha^{-1} P_2O_5), G1 – gyttja 10 000 kg ha^{-1}, G2 – gyttja 20 000 kg ha^{-1}, G3 – gyttja 80 000 kg ha^{-1}, V1 – vermicompost 10 000 kg ha^{-1}, V2 – vermicompost 20 000 kg ha^{-1}, CM1 – cattle manure 10 000 kg ha^{-1}, CM2 – cattle manure 20 000 kg ha^{-1}, GCF – gyttja + chemical fertilizer, VCF – vermicompost + chemical fertilizer, CMCF – cattle manure + chemical fertilizer.

* Means followed by different letters within the same column are significantly different according to the Tukey (HSD) test at the 5% significance level (p<0.05), ns – not statistically significant (p>0.05), blank letter cells indicate that the corresponding factor was not significant (ns) for that variable.

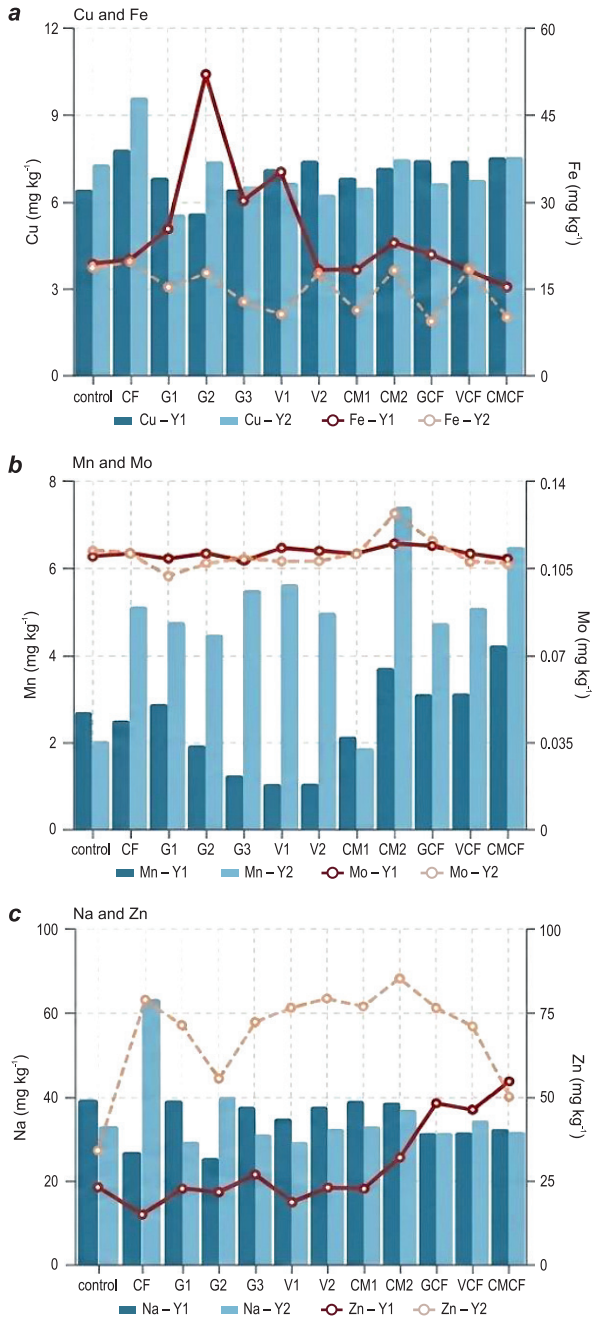


Fig. 3. Effects of different fertilizer applications on Cu and Fe (*a*), Mn and Mo (*b*) and Na and Zn (*c*) concentrations across two experimental years

amendments likely moderated its uptake. As shown in Table 5, the year effect for Cu was not significant, indicating that Cu accumulation in sunflower seeds was stable across the two growing seasons and not influenced by the contrasting climatic conditions of 2021 and 2022. This stability may be attributed to the relatively low mobility of Cu in soil and its strong binding to organic matter, making it less sensitive to year-to-year variation in precipitation or temperature. Nevertheless, the Y × FA interaction was highly significant ($p<0.01$), demonstrating that treatment effects on Cu varied considerably between years despite the absence of a significant main year effect (Table 5). In Y1, the control yielded the highest Cu (6.426 mg kg^{-1}), while in Y2 the control reached the highest value (9.630 mg kg^{-1}), suggesting that native soil Cu reserves were sufficient in the absence of fertilization (Table 6 and Figure 3*a*). Among organic treatments, gyttja-based applications generally depressed Cu compared with the control, possibly due to complexation of Cu with humic substances present in gyttja. The higher Cu values recorded with organomineral combinations (CMCF: 7.296 mg kg^{-1}) reflect the contribution of cattle manure to Cu availability, consistent with findings by Thomas et al. (2019), who reported that organic matter decomposition releases Cu into soil solution. Furthermore, organic matter from these applications can increase microbial exudates, thereby enhancing the bioavailability of micronutrients such as Cu to plants (Shiwakoti et al. 2019). Nevertheless, the increasing Cu concentration with higher manure doses indicates that organic inputs stimulate microbial exudates that release Cu into the soil solution (Dragičević et al. 2022).

Iron (Fe)

Iron concentrations ranged between 9.28 and 52.10 mg kg^{-1}, with the highest values recorded in the G2 (gyttja 20000 kg ha^{-1}) treatment, followed by V1 and CM2. Although Fe levels declined in the second year, the residual organic matter from manure and gyttja likely maintained adequate Fe availability. A highly significant year effect was detected ($p<0.01$, Table 5), with Y1 recording substantially higher Fe means (24.917 mg kg^{-1}) than Y2 (14.794 mg kg^{-1}). This suggests that the drier 2021 conditions, which may have promoted mild soil reducing conditions under intermittent irrigation, favored Fe availability. The exceptionally high Fe value in Y1 × G2 (52.10 mg kg^{-1}) drove much of the year-one advantage (Table 6). The Y × FA interaction was also highly significant ($p<0.01$, Table 5 and Figure 3*a*). Similarly, the application of CM1 resulted in a copper content of 6.0 and 5.8 mg kg^{-1} in cotton, which was notable, given that molybdenum content was 1.10 and 1.05 mg kg^{-1}, and zinc was 14.0 and 13.8 mg kg^{-1} (Niyazaliev et al. 2023). This agrees with findings by Taaime et al. (2024), who reported that organic inputs enhance Fe mobility by chelation and microbial mediation in soil.

Manganese (Mn)

Manganese content varied significantly between years and treatments, ranging from 1.02 to 7.40 mg kg^{-1}. The year effect for Mn was the largest among micronutrients ($p<0.01$, Table 5), with Y2 mean (5.410 mg kg^{-1}) far exceeding Y1 (1.777 mg kg^{-1}). Despite this large year-driven baseline shift, CM1 ranked highest in both years (Y1 × CM1: 2.144 mg kg^{-1}; Y2 × CM1: 7.398 mg kg^{-1}), demonstrating the consistent Mn-enhancing effect of cattle manure. The highest Mn accumulation occurred in CM1 (4.77 mg kg^{-1}), particularly during the second year (Table 6 and Figure 3*b*). The consistent increase in Mn with organic fertilizers indicates that manure improves soil redox conditions, promoting Mn solubility (Singh et al. 2024). Conversely, chemical fertilizer alone was less effective in maintaining Mn levels, likely due to limited microbial activity and reduced soil buffering capacity (Shiwakoti et al. 2019).

Molybdenum (Mo)

Molybdenum content varied between 0.099 and 0.127 mg kg^{-1}, with the highest values found in V2 and CM1 treatments. As indicated in Table 5, the year effect for Mo was not significant (ns), confirming that seasonal climatic variability between 2021 and 2022 did not meaningfully alter Mo accumulation in sunflower seeds. Molybdenum availability in soil is known to increase with soil pH and is relatively stable under the neutral to slightly alkaline conditions typical of Kahramanmaraş agricultural soils, which may explain the absence of a year effect. Despite the non-significant year main effect, the Y × FA interaction was highly significant ($p<0.01$, Table 5), indicating that the response of seed Mo concentration to specific fertilizer treatments differed between the two seasons. In Y1, V2 recorded the highest Mo (0.113 mg kg^{-1}), followed by CM1 and VCF (both 0.113 mg kg^{-1}). In Y2, CM1 yielded the highest Mo (0.127 mg kg^{-1}), followed by V2 (0.127 mg kg^{-1}), suggesting that vermicompost and cattle manure applications most consistently enhanced Mo uptake across both years (Table 6 and Figure 3*b*). This is likely linked to the role of these organic amendments in maintaining soil pH and promoting microbial activity, which facilitates Mo mineralization and uptake (Adeleke, Babalola, 2020). Mo availability is strongly influenced by soil pH and the presence of Ca and Mg (Sha et al. 2017), explaining the positive effects observed in manure treatments. Additionally, the application of organic amendments can paradoxically increase or decrease sodium concentration in plants depending on the specific soil conditions and the form of sodium present, with some studies indicating that high levels of soil organic matter can lead to strong retention of sodium (Sha et al. 2017). Additionally, the presence of certain fertilizers, particularly those containing calcium and magnesium, has been shown to create favorable conditions for molybdenum feeding in plants (Niyazaliev et al. 2023).

Sodium (Na)

Sodium levels ranged from 26.86 to 63.29 mg kg^{-1}, with the highest values in the control plots and the lowest in the chemical fertilizer treatment. These results indicate that excessive mineral fertilization may reduce Na uptake by altering ionic balance in the soil. As shown in Table 6, the year effect for Na was not significant (ns), indicating that the contrasting precipitation and temperature conditions between 2021 and 2022 did not result in a systematic shift in seed Na accumulation (Table 5). However, the Y × FA interaction was highly significant ($p<0.01$, Table 5), demonstrating markedly different treatment responses between years. In Y1, the control recorded the highest Na (39.283 mg kg^{-1}), whereas in Y2 it reached 63.287 mg kg^{-1} – the highest value across all treatment × year combinations. This pronounced increase in the unfertilized control in Y2 may reflect greater Na uptake from soil solution under wetter conditions, as Na mobility increases with soil moisture (Table 6 and Figure 3*c*). The consistent pattern across both years – where chemical fertilizer (CF) recorded the lowest Na and the control the highest – suggests that Na and essential mineral nutrient uptake are inversely related: fertilized plants may dilute Na through enhanced biomass and seed development. Among organic treatments, cattle manure applications (CM1, CM2) maintained intermediate Na levels in both years, while gyttja and vermicompost showed variable responses across seasons, consistent with the significant Y × FA interaction detected (Alzamel et al. 2022). The relatively stable Na levels under organic management align with findings of Mbarki et al. (2022), who emphasized that soil amendments influence Na retention and transport in plant tissues. Additionally, high sodium content can negatively impact fundamental plant processes, reducing growth and overall yield, as observed in studies on sorghum and sunflower plants (Hurtado et al. 2019). Furthermore, high concentrations of Na can compete with essential nutrients such as calcium and potassium, leading to deficiencies that impair plant growth and development (Lee et al. 2025).

Zinc (Zn)

Zinc levels ranged between 15.05 and 86.42 mg kg^{-1}, showing strong dependence on both treatment and year. Year significantly affected Zn ($p<0.01$, Table 5), with Y2 mean (76.967 mg kg^{-1}) more than three times higher than Y1 (23.139 mg kg^{-1}). Despite this large year effect, the treatment ranking was largely consistent: CM2 achieved the highest Zn in both Y1 (28.435 mg kg^{-1}) and Y2 (86.420 mg kg^{-1}), followed by CM1 in Y2 (81.952 mg kg^{-1}). The CM2 (20 000 kg ha^{-1}) and CMCF treatments achieved the highest Zn concentrations (Table 6 and Figure 3*c*). The pronounced Zn enrichment under manure-based fertilization can be attributed to increased organic ligands that enhance Zn bioavailability (Schweizer et al. 2018). Similar observations were made by Hinisli (2014), who reported that manure applications improve Zn uptake in leafy vegetables through chelation and reduced Zn fixation.

General discussion

The present study clearly demonstrates that fertilizer type exerts a profound influence on the nutritional composition of confectionery sunflower seeds. Organic and organomineral fertilizers – especially cattle manure and its combinations with chemical fertilizers – consistently improved both macro- and micronutrient concentrations compared with the chemical fertilizer alone. These results highlight the importance of integrating organic materials into conventional fertilization programs to optimize nutrient uptake and support sustainable crop nutrition strategies. The observed enhancement in N, P, K, Mg, and Ca concentrations under organic and organomineral fertilization treatments suggests that these applications may contribute to a more efficient nutrient availability and an improved soil environment for nutrient uptake over time. A particularly noteworthy finding is the strong year effect detected for most nutrients (Mg, P, Fe, Mn, Zn: $p<0.01$), underscoring the substantial influence of seasonal climatic variability on nutrient dynamics. The wetter 2022 season promoted organic matter mineralization and microbial activity, leading to generally higher nutrient concentrations in Y2. These environmental effects interacted significantly with fertilizer treatments (Y × FA: $p<0.01$ for all traits), confirming that the magnitude – though not the direction – of treatment responses varied between years. Main fertilizer effects are therefore interpreted in the context of within-year comparisons where interactions were significant. Similar synergistic effects have been reported by Alauddin et al. (2022) and Gholamhoseini et al. (2013) indicating that organic-mineral combinations optimize nutrient efficiency in oilseed crops. For micronutrients, increased levels of Zn, Mn, and Fe under organic and organomineral fertilization underscore the role of organic matter in improving trace element mobility and uptake. This is consistent with previous research on the bioavailability of micronutrients in organically managed soils (Niyazaliev et al. 2023, Šenk et al. 2023). The stable Mo and Na responses further demonstrate that balanced fertilization can prevent nutrient antagonism and ensure compositional stability in seeds.

CONCLUSION

The application of organic and organomineral fertilizers was associated with changes in macro- and micronutrient concentrations of confectionery sunflower seeds under the conditions of this two-year field experiment. The strong year × fertilizer application interactions observed for most nutrients demonstrate that fertilizer responses were season-dependent; consequently, recommendations should not be based solely on pooled treatment means. Cattle manure and cattle-manure-based organomineral fertilization were among the most consistently favorable treatments for N, P, Ca, Mg,

Mn, and Zn, whereas specific gyttja and vermicompost treatments were advantageous for selected nutrients. These findings support the use of organic materials as components of integrated nutrient management, but they do not justify a universal fertilizer recommendation across environments. This interpretation therefore emphasizes the interaction between fertilizer source and growing season and the need for multi-environment validation before making production-scale recommendations.

Author contributions

Z.A. – visualization, investigation, data curation, investigation. A.R.K. – conceptualization, methodology, supervision, formal analysis, software, writing-original draft preparation. T.E. – validation, writing-original draft preparation, reviewing and editing. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest

The authors ensure that they have neither professional nor financial connections related to the manuscript sent to the Editorial Board.

REFERENCES

Adeleke, B.S., Babalola, O.O. 2020 'Oilseed crop sunflower (*Helianthus annuus*) as a source of food: Nutritional and health benefits', *Food Science & Nutrition,* 8(9)**,** 4666, available: https://doi.org/10.1002/fsn3.1783

Al-Tawarah, B., Alasasfa, M.A., Mahadeen, A.Y. 2023 'Efficacy of compost and vermicompost on growth, yield and nutrients content of common beans crop (*Phaseolus vulgaris* L.)', *Journal of Ecological Engineering,* 25(2), 215-226, available: https://doi.org/10.12911/22998993/176862

Alauddin, M., Rahman, M.K., Ali, H.M.Z. 2022 'Influence of cow dung and NPK fertilizers on macronutrients and oil content of sunflower (*Helianthus annuus* L.)', *Journal of Biodiversity Conservation and Bioresource Management,* 8(2)**,** 51-60, available: https://doi.org/10.3329/jbcbm.v8i2.63817

Alzamel, N.M., Taha, E.M.M., Bakr, A.A.A., Loutfy, N. 2022 'Effect of organic and inorganic fertilizers on soil properties, growth yield, and physiochemical properties of sunflower seeds and oils', *Sustainability,* 14(19)**,** 12928, available: https://doi.org/10.3390/su141912928

Çitak, S., Sönmez, S., Koçak, F., Yasin, S. 2011 'Effects of vermicompost and farmyard manure applications on spinach (*Spinacia oleracea* var. L.) growth and soil fertility', *Derim,* 28(1)**,** 56-69, available: https://dergipark.org.tr/tr/pub/derim/issue/4570/62629

Dragičević, V., Brankov, M., Stoiljković, M., Tolimir, M., Kanatas, P., Travlos, I., Simić, M. 2022 'Kernel color and fertilization as factors of enhanced maize quality', *Frontiers in Plant Science,* 13, 1027618, available: https://doi.org/10.3389/fpls.2022.1027618

Doğan, Y., Togay, N., Togay, Y. 2019 'Determining irrigation scheduling and different manure sources of yield and nutrition content on maize (*Zea mays* L.) cultivation', *Applied Ecology and Environmental Research*, 17(2): 1559-1570, available: https://doi.org/10.15666/aeer/1702_15591570

Ghasemi-Tabasi, H., Darzi, M.T., Hadi, M.R. 2023 'The effect of utilizing different types of organic and bio-fertilizers on growth, elements concentration, seed yield and essential

oil of *Coriandrum sativum* L.', *Legume Research – An International Journal,* 47(9)**,** 1497-1505, available: https://doi.org/10.18805/lrf-770

Gholamhoseini, M., Ghalavand, A., Khodaei-Joghan, A., Dolatabadian, A., Zakikhani, H., Farmanbar, E. 2013 'Zeolite-amended cattle manure effects on sunflower yield, seed quality, water use efficiency and nutrient leaching', *Soil and Tillage Research,* 126, 193-202, available: https://doi.org/10.1016/j.still.2012.08.002

Hinisli, N. 2014 'The effects of vermicompost fertilizer on lettuce growth and its comparison with some other organic fertilizers', (Master's Thesis, Institute of Science)', Tekirdağ Namık Kemal University, Institute of Science. Tekirdağ.

Hurtado, A.C., Chiconato, D.A., Prado, R.D.M., Sousa, G.D.S., Felisberto, G. 2019 'Silicon attenuates sodium toxicity by improving nutritional efficiency in sorghum and sunflower plants', *Plant Physiology and Biochemistry,* 142, 224-233, available: https://doi.org/10.1016/j.plaphy.2019.07.010

Kandil, E., Abdelsalam, N.R., Mansour, M.A., Ali, H.M., Siddiqui, M.H. 2020 'Potentials of organic manure and potassium forms on maize (*Zea mays* L.) growth and production', *Scientific Reports,* 10(1)**,** 8752, available: https://doi.org/10.1038/s41598-020-65749-9

Kaya, A., Erdönmez, H. 2020 'Effect of different fertilizer forms and doses on seed germination and seedling development of soybean (*Glycine max* (L.) Merrill)', *Turkish Journal of Nature and Science,* 9(Special Issue), 73-79, available: https://doi.org/10.46810/tdfd.730641

Kaya, A.R., Yildirim, M., Çiftçi Sakin, S. 2024*a* 'The effect of liquid seaweed of organic origin on seed germination and seedling development of some winter cereal species', *Journal of Agriculture and Nature,* 27(6)**,** 1434-1442, available: https://doi.org/10.18016/ksutarimdoga.vi.1441954

Kaya, A.R., Yildirim, M., Çiftçi Sakin, S. 2024*b* 'A study of effects of organic origin liquid seaweed on germination radicle and plumule growth in winter cereal genus', *Turkish Journal of Nature and Science,* 13(2)**,** 114-120, available: https://doi.org/10.46810/tdfd.1413556.

Koskey, G., Avio, L., Turrini, A., Sbrana, C., Bàrberi, P. 2022 'Biostimulatory effect of vermicompost extract enhances soil mycorrhizal activity and selectively improves crop productivity', *Plant and Soil,* 484, 183-199, available: https://doi.org/10.1007/s11104-022-05783-w

Lee, J., Jo, N.-Y., Shim, S.-Y., Le, T.Y.L., Jeong, W., Kwak, K.W., Choi, H.S., Lee, B.-O., Kim, S.-R., Lee, M.-G., Hwang, S. 2025 'Impact of organic liquid fertilizer on plant growth of Chinese cabbage and soil bacterial communities', *Scientific Reports,* 15(1)**,** 10439, available: https://doi.org/10.1038/s41598-025-95327-w

Littell, R.C., Milliken, G.A., Stroup, W.W., Wolfinger, R.D., Schabenberger, O. 2006. SAS for Mixed Models, 2nd ed. SAS Institute Inc., Cary, NC.

Mbarki, S., Talbi, O., Skalický, M., Vachová, P., Hejnák, V., Hnilička, F., Al-Ashkar, I., Abdelly, C., Rahman, M.A., Sabagh, A.E., Tlustoš, P. 2022 'Comparison of grain sorghum and alfalfa for providing heavy metal remediation of sandy soil with different soil amendments and salt stress', *Frontiers in Environmental Science,* 10, 1022629, available: https://doi.org/10.3389/fenvs.2022.1022629

Niyazaliev, B., Ismailov, J., Tillabekov, B. 2023 'Effect of copper, zinc and molybdenum micro elements in plants when using granular and liquid nitrogen fertilizer with micro elements made from local raw materials', *BIO Web of Conferences,* 78, 03005, available: https://doi.org/10.1051/bioconf/20237803005

Petraru, A., Ursachi, F., Amariei, S. 2021 'Nutritional characteristics assessment of sunflower seeds, oil and cake. perspective of using sunflower oilcakes as a functional ingredient', *Plants,* 10(11)**,** 2487, available: https://doi.org/10.3390/plants10112487

Puraikalan, Y., Scott, M.I. 2023 'Sunflower seeds (*Helianthus annuus*) and health benefits: A Review', *Recent Progress in Nutrition,* 3(3)**,** 1-5, available: https://doi.org/10.21926/rpn.2303010

Schweizer, S.A., Seitz, B., Heijden, M.G.A.V.D., Schulin, R., Andy, S. 2018 'Impact of organic and conventional farming systems on wheat grain uptake and soil bioavailability of zinc and cadmium', *The Science of the Total Environment,* 639, 608-616, available: https://doi.org/10.1016/j.scitotenv.2018.05.187

Šenk, M., Simić, M., Milojković-Opsenica, D., Brankov, M., Tolimir, M., Kodranov, I., Dragičević, V. 2023 'Common millet and soybean intercropping with bio-fertilizer as sustainable practice for managing grain yield and quality', *Frontiers in Nutrition,* 10, 1267928, available: https://doi.org/10.3389/fnut.2023.1267928

Sha, Z., Chu, Q., Zhao, Z., Yue, Y., Linfang, L., Yuan, J., Cao, L. 2017 'Variations in nutrient and trace element composition of rice in an organic rice-frog coculture system', *Scientific Reports,* 7(1), 15706, available: https://doi.org/10.1038/s41598-017-15658-1

Shiwakoti, S., Zheljazkov, V.D., Gollany, H.T., Kleber, M., Xing, B. 2019 'Micronutrients decline under long-term tillage and nitrogen fertilization', *Scientific Reports,* 9(1), 12020, available: https://doi.org/10.1038/s41598-019-48408-6

Silva, W.V.D., Taveira, J.H.D.S., Fernandes, P B., Silva, P.C., Costa, A.B.G.D., Costa, C.M., Giongo, P.R., Corioletti, N.S.D., Gurgel, A.L.C. 2023 'Organic and mineral fertilization determining the agronomic performance of sunflower cultivars and soil chemical attributes', *Revista Brasileira de Engenharia Agrícola e Ambiental,* 27(12)**,** 927-933, available: https://doi.org/10.1590/1807-1929/agriambi.v27n12p927-933

Singh, P., Suyal, D.C., Kumar, S., Singh, D.K., Goel, R. 2024 'Long-term organic farming impact on soil nutrient status and grain yield at the foothill of Himalayas', *Frontiers in Environmental Science,* 12, 1378926, available: https://doi.org/10.3389/fenvs.2024.1378926

Sireesha, A., Sreenivas, C., Usharani, T.R., Satyanarayana, P.V. 2019 'Effect of different levels of fertilizer application along with organic manure on maize yield and soil fertility', *International Journal of Current Microbiology and Applied Sciences,* 8(10)**,** 2137, available: https://doi.org/10.20546/ijcmas.2019.810.248

Steel, R.G.D., Torrie, J.H., Dickey, D.A. 1997. Principles and Procedures of Statistics: A Biometrical Approach, 3rd ed. McGraw-Hill, New York.

Taaime, N., Mejahed, K.E., Oukarroum, A., Choukr-Allah, R., Pittelkow, C.M., Bouabid, R., Gharous, M.E. 2024 'Residual effects of compost and manure fertilizers on quinoa production and nutrient uptake', *Journal of Soil Science and Plant Nutrition,* 24, 4338-4348, available: https://doi.org/10.1007/s42729-024-01838-2

Thomas, C.L., Acquah, G., Whitmore, A.P., Mcgrath, S.P., Haefele, S.M. 2019 'The effect of different organic fertilizers on yield and soil and crop nutrient concentrations', *Agronomy,* 9(12)**,** 776, available: https://doi.org/10.3390/agronomy9120776