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Effects of phosphorus and zinc application on the growth and oil ratio of safflower (*Carthamus tinctorius* L.) under calcareous soil conditions

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Abstract

In order to evaluate the effect of phosphorus and zinc fertilizer on the elements concentration, growth, and oil ratio of safflower (*Carthamus tinctorius* L.) under calcareous soil conditions, this study was conducted at the farm of the Agricultural Research Station in Qaragool, during the winter season of 2022-2023. A randomized complete block design (RCBD) with three replicates was used to carry out a factorial experiment. The factors examined included the factor P with three levels of phosphorus fertilizer (0, 100, 200) kg P_2O_5 ha^{-1} from the source of triple superphosphate and factor Zn with three levels of zinc spraying in concentrations of (0, 15, 30) kg Zn ha^{-1} from the source of zinc sulfate. The results of this investigation confirm that both levels of (200 kg P_2O_5 ha^{-1} + 30 kg Zn ha^{-1} and 100 kg P_2O_5 ha^{-1} + 30 kg Zn ha^{-1}) have a significant impact on some characteristics of yield and its components of the plant, for example, plant height (141.667 cm), main branches $plant^{-1}$ (30.000), number of heads $plant^{-1}$ (95.667), number of seeds $head^{-1}$ (19.000), weight of 100 seeds (3.757g), and seed yield (13.450 *Mg* ha^{-1}). Moreover, variance analysis showed that the interaction between different levels of phosphorus with zinc fertilizer has a significant effect on nutrient content in the rhizosphere soil, nutrient content in the seed, and the shoot of the safflower plant. Also, the oil content (42.660%) in the seed and fatty acids such as linoleic acid (65.620%) and linolenic acid (0.097%) in the seed oil of safflower are affected by the interaction between different levels of phosphorus and zinc fertilizer.

Keywords: Fatty acids, Nutrient content, Oil ratio, Safflower, Yield

Introduction

Safflower is a major oil-producing crop worldwide. In Iraq, it is cultivated during the winter season. Safflower (*Carthamus tinctorius* L.) is an oilseed crop that belongs to the Compositae or Asteraceae family. It is widely grown for its oil. Also, it was mainly produced for the flowers, which were used to color foods [1].

According to hull types of seeds, the seed oil content ranges from 20% to 45%. The oil is high in linoleic acid, an unsaturated fatty acid that aids in lowering the cholesterol level in the blood [2]. The cultivation of this crop is crucial as it stands out as one of the few oilseed crops suitable for Iraq's winter climate, whereas most oilseed crops grown in Iraq are summer crops. Additionally, it requires minimal water and can withstand salty and drought conditions [3]. One of the most important factors in obtaining high safflower output is effective nutrient management [4]. Phosphorus (P) is an essential element required for plant growth and productivity. This element plays a role in an array of processes, including the synthesis of biomolecules and the formation of high-energy molecules, nucleic acid synthesis, photosynthesis, glycolysis, respiration, membrane synthesis and stability, enzyme activation/inactivation, redox reactions, signaling, and carbohydrate metabolism [5, 6]. Numerous studies have shown that adding phosphorous to the soil enhances plant growth and has a beneficial effect. Plant height went up from (96.23 to 101.97) cm as the phosphorus level increased from (40 to 60) kg P ha^{-1} [7]. Moreover, adding phosphorus fertilizer had an impact on vegetative growth, yield components, and oil content of safflower [8]. Several key factors directly affect crop yield, including soil fertility, the availability of macronutrients and micronutrients in the soil, input application, and crop management. To enhance crop production, it is possible to either expand the cultivated area or increase its yield per unit area. Under the present situation, the more appropriate choice is to achieve a higher yield per unit area. Micronutrients are regarded as essential plant nutrients taken up and consumed by the plants in relatively minor amounts. These micronutrients play an eminent role in plant growth, development, and metabolism [9]. However, these micronutrients are required in low quantities; their deficiencies are responsible for low quality and low productivity of safflower [10]. Zinc (Zn) plays a key role in regulatory cofactors of different enzymes and proteins in many biochemical pathways. It can help in high productivity in oilseed crops [11]. Zinc is essential for crop nutrition as needed for numerous metabolic processes and oxidation-reduction reactions. Its deficiency will reduce the growth and yields of the crop [12].

The safflower growth and mineral nutrient uptake to be studied comprehensively, because safflower seed is commonly used to improve digestive health or relieve constipation. Safflower seed may also help lower total blood cholesterol and low-density lipoprotein cholesterol levels, which may help reduce the risk of heart disease. This study aims to investigate the impact of different amounts of phosphorus and zinc fertilizer on some growth traits of safflower.

Materials and Methods

The present investigation was carried out of Qaragool, farm of Agricultural Research Station (35° 21' 29" N, 45° 37' 19" E 556 m above sea level) in Sulaimani Governorate, Kurdistan Region-Iraq, during winter season of 2022-2023 to study the effect of phosphorus and zinc on the growth and oil ratio of safflower (*Carthamus tinctorius* L.) "Gilla" variety. For determining the physical and chemical characteristics of soil in the study area, the soil samples were taken at (0 to 40 cm) depths; the soil samples were allowed to air dry, passed through a 2 mm sieve, and kept in plastic bottles until analyzed. The soil type was silty clay; the physical and chemical properties of the soil of the field experimental site are shown in Table 1. The experimental design was a factorial experiment, laid out in a completely random block design (RCBD) with three replications. It included two factors. The first factor was phosphorous fertilizer with three levels (0, 100, and 200) kg P_2O_5 ha^{-1} as soil application, and the second factor was three levels of zinc fertilizer (0, 15, and 30) kg Zn ha^{-1} used as foliar application. The used treatments are symbolized as follows: T1=control (P0Zn0), T2=100 kg P_2O_5 ha^{-1} (P1Zn0), T3=200 kg P_2O_5 ha^{-1} (P2Zn0), T4=15 kg Zn ha^{-1} (P0Zn1), T5=100 kg P_2O_5 ha^{-1} + 15 kg Zn ha^{-1} (P1Zn1), T6=200 kg P_2O_5 ha^{-1} + 15 kg Zn ha^{-1} (P2Zn1), T7=30 kg Zn ha^{-1} (P0Zn2), T8=100 kg P_2O_5 ha^{-1} + 30 kg Zn ha^{-1} (P1Zn2), T9=200 kg P_2O_5 ha^{-1} + 30 kg Zn ha^{-1} (P2Zn2).

The farm size was (7 m × 15 m) divided manually into plots, each replicate consists of nine experimental unit (1 m × 1 m) in size, and within each experimental unit were three lines, the length of the planted line one meter, (0.05 m) distance was left then seeds were sown, and the distance from one line to the next (0.45 m) and (0.3 m) between plant to plant in the same line, (0.5 m) distance between experimental units was left, and one meter between blocks. Triple superphosphate and zinc sulfate were used as sources of (P and Zn) fertilizers, respectively. The phosphate fertilizer was added in two doses; the first dose was at the sowing date, and the last dose was applied after 94 days from sowing. Half of the total zinc sulfate was sprayed at 117 days. After sowing time, the remaining half was sprayed at 20 days, after the initial application. The experimental field was ploughed and well leveled, the weeding was accomplished manually several times for all treatments equally and as needed during the growing season. The safflower seeds were planted in (5 cm) depth, the seeds were sown manually on 8th December 2022, and harvesting was done when the plants reached full maturity on 8th July 2023. Data on vegetative and reproductive growth parameters such as (plant height, main branches $plant^{-1}$, number of heads $plant^{-1}$, number of seeds $head^{-1}$, weight of 100 seeds, seed yield), contents of phosphorus, zinc and iron in soil rhizosphere, phosphorus, zinc and iron content in seeds and shoots, oil content (%), linoleic acid (%) and linolenic acid (%) in seeds were recorded during the course of study for each experimental unit separately. Available P was assayed by extracting P from soil rhizosphere with 0.5 M $NaHCO_3$ (pH 8.5), according to the procedure of [13]. Available Zn and Fe content of soil rhizosphere was extracted with DTPA-TEA (pH 7.3) extractant following the method of [14]. Wet digestion method using HNO_3-$HClO_4$ in the ratio of (2:1) was followed to determine P, Zn, and Fe from the plant material as mentioned by [15]. Phosphorus content was read on a spectrophotometer, and the content of zinc and Fe was measured with an atomic absorption spectrophotometer (AAS). The oil content of safflower seeds was determined by using the Soxhlet apparatus as mentioned by [16].

The fatty acid compositions were analyzed according to [17] by GC–MS and GC-FID instruments.

The collected data were statistically analyzed for all measured variables using the statistical program package (XLSTAT software), and the differences were compared at the 5% significance level. The Duncan's multiple range test was used to compare among means [18].

Table (1): The physical and chemical properties of the soil samples of the field experimental site

<table>
<tr><th colspan="9">Physical properties</th></tr>
<tr><th colspan="5">Particle size distribution (PSD) g kg^{-1}</th><th colspan="4">Bulk density *Mg* m^{-3}</th></tr>
<tr><th>Sand</th><th>Silt</th><th>Clay</th><th colspan="2">Texture class</th><td colspan="4" rowspan="2">1.65</td></tr>
<tr><td>25.60</td><td>496.45</td><td>477.95</td><td colspan="2">Silty Clay</td></tr>
<tr><th colspan="9">Chemical properties</th></tr>
<tr><th>pH</th><th colspan="2">EC dS m^{-1} at 25 C°</th><th colspan="6">Soluble ions mmol L^{-1}</th></tr>
<tr><td rowspan="2">7.82</td><td colspan="2" rowspan="2">0.41</td><th>Ca^{2+}</th><th>Mg^{2+}</th><th>Na^{+}</th><th>K^{+}</th><th>HCO_3^{-}</th><th>SO_4^{2-}</th></tr>
<tr><td>2.98</td><td>0.71</td><td>0.97</td><td>0.95</td><td>3.87</td><td>0.91</td></tr>
<tr><th>Organic matter (OM)</th><th colspan="2">Total $CaCO_3$ equivalent</th><th colspan="3">Available P</th><th>Available Zn</th><th colspan="2">Available Fe</th></tr>
<tr><th colspan="3">g kg^{-1}</th><th colspan="3">µg g^{-1} soil</th><th colspan="3">mg kg^{-1}</th></tr>
<tr><td>15.30</td><td colspan="2">99.32</td><td colspan="3">6.12</td><td>0.96</td><td colspan="2">2.53</td></tr>
</table>

Results and Discussion

Effect of phosphorus, zinc fertilizer levels, and their interactions on some nutrient content in the rhizosphere soil:

Phosphorus content in the soil rhizosphere

Table 2 shows the effect of phosphorus, zinc levels, and their interaction on phosphorus concentration in the rhizosphere at ($p \leq 0.05$). Depending on the effect of phosphorus concentration in the rhizosphere, no significant improvement in P concentration was observed with the application of P levels.

However, the effect of zinc levels on phosphorus concentration was found to be significant. The highest mean value of phosphorus concentration in the rhizosphere was (2.808%) obtained with zinc-level (Zn2) compared with the control treatment that recorded (1.275%).

As well as, The interaction effect between levels of phosphorus and zinc fertilizer in phosphorus concentration in the rhizosphere was found to be significant at ($P \leq 0.05$). The maximum concentration of phosphorus was (3.170%) recorded by (P2Zn2), and the minimum concentration of phosphorus was (0.950%), which was recorded by (P2Zn0). The nature and concentration of nutrients in the rhizosphere depend on soil type, soil fertility, and crop intensity. Likewise, the absorption and utilization of nutrients by plants are impacted by various factors related to both the soil and the plants, as well as their interactions. Physical, chemical, and biological alterations in the rhizosphere are associated with enhanced concentration of phosphorus in the root vicinity and, consequently, its uptake [19].

Zinc content in the soil rhizosphere

Data present in Table 2 explain that the Zn concentration in the rhizosphere was influenced significantly by phosphorus, zinc levels, and their interactions at ($p \leq 0.05$). Based on the applied levels of phosphorus fertilizer, the phosphorus level (P2) was significantly different from other treatments, which obtained the highest mean rate of Zn concentration in the rhizosphere (3.773 mg kg^{-1}), while the lowest mean rate was (3.043 mg kg^{-1}) recorded at the control. At the same time, the zinc level (Zn2) was significantly different from other treatments, which obtained the highest mean rate of Zn concentration in the rhizosphere (4.380 mg kg^{-1}), while the lowest mean rate was (2.130 mg kg^{-1}) recorded at the control.

Table (2): Effect of phosphorus, zinc, and their interactions on some nutrient content in the rhizosphere soil of safflower

Phosphorus content in the soil rhizosphere soil %				
Phosphorus Levels	**Zinc Levels**			
	Zn 0	**Zn 1**	**Zn 2**	**Effect of Phosphorus**
P 0	1.420 de	1.775 cde	2.485 abc	1.893 a
P 1	1.455 de	1.380 de	2.770 ab	1.868 a
P 2	0.950 e	1.960 bcd	3.170 a	2.027 a
Effect of Zinc	1.275 b	1.705 b	2.808 a	
Zinc content in the soil rhizosphere mg kg^{-1}				
P 0	1.315 d	3.190 b	4.625 a	3.043 b
P 1	2.315 c	2.810 bc	4.155 a	3.093 b
P 2	2.760 bc	4.200 a	4.360 a	3.773 a
Effect of Zinc	2.130 c	3.400 b	4.380 a	
Iron content in the soil rhizosphere mg kg^{-1}				
P 0	38.200 b	36.900 b	25.500 c	33.533 b
P 1	41.300 b	24.300 c	57.300 a	40.967 a
P 2	35.350 b	20.100 c	59.550 a	38.333 ab
Effect of Zinc	38.283 b	27.100 c	47.450 a	

Means within a column, row, and their interactions separately, followed with the same letters, are not significantly different according to Duncan's multiple range tests at ($p \leq 0.05$).

The most favorable interaction between phosphorus and zinc levels in Zn concentration of rhizosphere was (4.625 mg kg^{-1}) obtained by (P0Zn2) and was significantly highest than all treatments, while the lowest mean value of soil Zn concentration was (1.315 mg kg^{-1}) recorded from (P0Zn0). The amount of Zn in the rhizosphere is important for efficient uptake by plant roots [20].

Iron content in the soil rhizosphere

Table 2 demonstrated that phosphorus, zinc levels, and their interactions were significantly impacted by Fe concentration in the rhizosphere. Depending on the applied levels of phosphorus fertilizer, the phosphorus level (P1) was significantly different from other treatments, which obtained the highest mean value of Fe concentration in the rhizosphere (40.967 mg kg^{-1}), while the lowest mean rate was (33.533 mg kg^{-1}) recorded at the control. About zinc fertilizer, zinc-level (Zn2) was significantly different from other treatments, which observed the maximum mean value of Fe concentration in the rhizosphere (47.450 mg kg^{-1}), and the minimum mean value of Fe concentration was (27.100 mg kg^{-1}) recorded by (Zn1) treatment. Regarding the interaction between applied phosphorus and zinc levels, significant differences were found between phosphorus and zinc in the Fe concentration of the rhizosphere, at ($P \leq 0.05$). The highest concentration of Fe was (59.550 mg kg^{-1}) recorded by (P2Zn2), while the lowest concentration of Fe was (20.100 mg kg^{-1}), which was recorded by (P2Zn1). Soil and plant properties, and interactions of roots with microorganisms and the surrounding soil control micronutrient availability in the rhizosphere. In addition, micronutrient-efficient crops and genotypes can increase the available nutrient fraction and hence increase micronutrient uptake [21].

Effect of phosphorus, zinc fertilizer levels, and their interactions on some vegetative growth criteria of a safflower plant:

Plant height (cm)

Table 3 indicates that the application levels of phosphorus and zinc fertilizers had a significant impact on plant height ($P \leq 0.05$). As the levels of phosphorus rose, there was a notable increase in plant height. The height of the plant varied between (133.778 to 135.667) cm; the highest measurement was found in treatment (P2), and the lowest was in the control. Based on the impact of zinc fertilization on plant height, the zinc fertilization rate (Zn2) showed the maximum plant height (140.111 cm), while the minimum value of plant height (130.111 cm) was observed in the control. Regarding the interaction between phosphorus and zinc fertilizer levels application on plant height, significant differences were found at ($P \leq 0.05$). The plant height ranged from (130.000 to 141.667) cm, the highest value of plant height was recorded at (P2Zn2), while the lowest value of plant height was recorded at (P1Zn0) and (P2Zn0). Our results are supported by [7], who found that the higher levels of phosphorus likely led to an increase in plant height because phosphorus is essential for various physiological processes, including photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement, and development of meristematic tissues that aid in enhancing plant growth characteristics. These results are also going with those for zinc, and were obtained by [22, 23, 24]. They found that the application of zinc fertilizer significantly affected the plant height (cm) of safflower.

Zinc leads to increased plant yield through positive physiological effects, such as impact on the metabolism of plant cells [25, 26].

Main branches of plant^{-1} and the number of heads of plant^{-1}

The main branches per plant of safflower were affected significantly by application of phosphorus and zinc fertilizer levels at ($P \leq 0.05$). Table 3 demonstrates that the rates of phosphorus and zinc fertilizer application significantly affected the main branches per plant of safflower; the main branches per plant of safflower significantly increased with the applied phosphorus rates. The maximum value was obtained at (P1), with a mean of 24.000, while the minimum value was recorded at control was 22.000. The impact of the zinc fertilization rate on the main branches shows significant different, the highest value was recorded at (Zn2) level with a mean of (29.111), while the lowest value (19.333) was obtained at control. Regarding the application of interaction between phosphorus and zinc fertilizer rates on the main branches of plant^{-1}, significant differences were found at ($P \leq 0.05$). The main branches ranged from (18.333 to 30.000), the highest values were recorded from (P2Zn2 and P1Zn2), while the lowest values were recorded from the control.

Meanwhile, the number of heads of plant^{-1} affected by the application of phosphorus and zinc fertilizer is significantly Table 3. The phosphorus rate (P2) showed the maximum value (83.444) heads plant^{-1}, while the minimum value (69.111) heads plant^{-1} was observed from the control. Based on the effect of zinc fertilization rate on the number of heads, the number of heads per plant^{-1} affected by the application of zinc rate fertilizer, the highest value was recorded at (Zn2), with a mean of 93.222, while the minimum value (56.667) was obtained at the control. About the interaction between the application of phosphorus and zinc fertilizer rates on the number of heads per plant^{-1}, significant differences were found at ($P \leq 0.05$). The number of heads ranged from (44.667 to 95.667) heads per plant^{-1}, the lowest value was observed from (P0Zn0), whereas the highest value was observed from (P1Zn2). These results agree with the results obtained by [7, 27, 28] for phosphorus. They found that phosphorus application significantly influenced the growth analysis of safflower and its components. Also, our results are consistent with those obtained by [22, 24, 29] who found that the application of zinc significantly increased the growth yield of safflower plants.

Table (3): Effect of phosphorus, zinc, and their interactions on some vegetative growth criteria of safflower

Plant height (cm)				
Phosphorus Levels	**Zinc Levels**			
	Zn 0	**Zn 1**	**Zn 2**	**Effect of Phosphorus**
P 0	130.333 d	132.667 cd	138.333 b	133.778 b
P 1	130.000 d	133.333 c	140.333 ab	134.556 ab
P 2	130.000	135.333 c	141.667 a	135.667 a

	d			
Effect of Zinc	130.111 c	133.778 b	140.111 a	
Main branches plant^{-1}				
P 0	18.333 b	20.333 b	27.333 a	22.000 b
P 1	20.333 b	21.667 b	30.000 a	24.000 a
P 2	19.333 b	21.000 b	30.000 a	23.444 ab
Effect of Zinc	19.333 b	21.000 b	29.111 a	
Number of heads plant^{-1}				
P 0	44.667 d	73.667 c	89.000 ab	69.111 c
P 1	52.333 d	80.667 bc	95.667 a	76.222 b
P 2	73.000 c	82.333 bc	95.000 a	83.444 a
Effect of Zinc	56.667 c	78.889 b	93.222 a	

Means within a column, row, and their interactions separately, followed with the same letters, are not significantly different according to Duncan's multiple range tests at ($p \leq 0.05$).

Effect of phosphorus, zinc fertilizer levels, and their interactions on some reproductive growth criteria of a safflower plant:

Number of seeds head^{-1} and weight of 100 seeds (g)

Table 4 shows the effect of phosphorus, zinc fertilization rate, and their interactions on the number of seeds head^{-1}. The phosphorus fertilization significantly influenced the number of seeds ($P \leq 0.05$). The phosphorus rate (P2) showed the highest mean of seeds head^{-1} was (17.889), while the control recorded the lowest mean value, which was (16.444). Relying on the effect of zinc fertilization rate on the number of seed head^{-1}, significant differences were observed among the treatments at ($P \leq 0.05$). The higher mean value (18.667) was recorded with the level (Zn2) compared to other zinc levels. Additionally, concerning the interaction effect between applied phosphorus and zinc levels at ($P \leq 0.05$). The maximum number of seed head^{s} was 19.000, resulting from the interaction effect of (P2Zn2), while the minimum mean value (14.667) was recorded with (P0Zn1). While for the weight of 100 seeds (g), Table 4 shows the effect of phosphorus, zinc fertilization rate, and their interactions on the weight of 100 seeds significantly influenced at ($P \leq 0.05$).

The phosphorus rate (P1) showed the maximum mean weight of 100 seeds (3.169 g); however, the minimum mean value recorded with the control was 2.928 g. Also, the effect of zinc fertilization rate on the 100-seed weight (g), significant differences among the treatments at ($P \leq 0.05$). The higher mean value (3.521 g) was recorded with the zinc level (Zn2), and the lower mean value (2.568 g) was recorded with the control. In relation to the interaction between phosphorus and the applied zinc rates, the maximum 100-seed weight (g) was (3.757g), resulting from the interaction effect by (P1Zn2), compared with (P1Zn0), which recorded the minimum 100-seed weight (g) was (2.493 g).

This may be related to the same reasons mentioned previously; similar results were obtained by [7, 27, 30] for phosphorus, they found that the application of phosphorus was affected significantly in the number of seed heads^{-1} and the weight of 100 seeds of safflower. While the results were obtained by [22, 24, 31] for zinc rates, they found that the application of zinc rate fertilizer significantly affected the number of seed heads and the weight of 100 seeds of safflower.

Seed yield (*M*g ha^{-1})

About the illustrated data in Table 4 for seed yield (*M*g ha^{-1}). This effect has shown no similar trends to those in 100-seed weight. No significant improvement in seed yield was also observed by application the phosphorus levels. These results are in agreement with the results reported by [32].

The effect of zinc on seed yield was found to be significant. The maximum and minimum mean value of seed yield were (12.517 *M*g ha^{-1} and 8.983 *M*g ha^{-1}) recorded from (Zn2) and control, respectively, and the interaction effect of phosphorus and zinc levels on seed yield was found to be significant at ($P<0.05$). The seed yield in this study varied from 8.650 *M*g ha^{-1} to 13.450 *M*g ha^{-1}. The maximum of seed yield was produced by (P1Zn2), recorded (13.450 *M*g ha^{-1}), while the minimum seed yield was produced by (P1Zn0), which recorded (8.650 *M*g ha^{-1}). Phosphorus is the most interesting primary nutrient because P deficiency limits crop growth and yield in many regions in the world [33]. The application of phosphorus is important because it is an essential plant macronutrient involved in numerous molecules components. Molecules that contain P are DNA, RNA, proteins, lipids, sugars, ATP, ADP, and NADPH. In other words, P is central to a majority of the molecular constituents needed for the functioning of plant cells [34]. The results are in harmonic with the findings by [22, 23, 35] about zinc rate application. Also, [36] indicated that zinc sulfate application under water stress conditions increased seed yield more than the control plots. Zinc is crucial for many enzymes that play a vital role in nitrogen metabolism, energy transfer, and protein synthesis [12].

Table (4): Effect of phosphorus, zinc, and their interactions on some reproductive growth criteria of safflower

Number of seeds head^{-1}				
Phosphorus Levels	Zinc Levels			
	Zn 0	Zn 1	Zn 2	Effect of Phosphorus
P 0	16.333 bc	14.667 d	18.333 a	16.444 b
P 1	15.333 cd	17.667 ab	18.667 a	17.222 ab
P 2	16.333 bcd	18.333 a	19.000 a	17.889 a
Effect of Zinc	16.000 b	16.889 b	18.667 a	
Weight of 100 seeds (g)				
P 0	2.527 d	2.967 c	3.290 b	2.928 b
P 1	2.493 d	3.257 b	3.757 a	3.169 a
P 2	2.683 cd	2.947 c	3.517 ab	3.049 ab

Effect of Zinc	2.568 c	3.057 b	3.521 a	
Seed yield (*Mg* ha^{-1})				
P 0	9.400 b	9.100 b	11.700 ab	10.067 a
P 1	8.650 b	11.200 ab	13.450 a	11.100 a
P 2	8.900 b	11.400 ab	12.400 a	10.900 a
Effect of Zinc	8.983 c	10.567 b	12.517 a	

Means within a column, row, and their interactions separately, followed by the same letters, are not significantly different according to Duncan's multiple range tests at ($p \leq 0.05$).

Effect of phosphorus, zinc fertilizer levels, and their interactions on some nutrient content in the seed and shoot of a safflower plant

Phosphorus content in the seed and shoot

From the represented data in Table 5, it appears that significant differences were registered at ($P \leq 0.05$), for phosphorus content in the seed influenced by both applied levels of phosphorus and zinc fertilizer. Considering the effect of phosphorus, the maximum and minimum mean values of phosphorus content in the seed were (0.219% and 0.203%), recorded from application of (P2 and P1) treatments, respectively. When considering the effect of zinc, the highest significant mean value of P content in the seed was 0.241%, which was recorded from application of Zn2, while its lowest mean value was 0.191%, which was obtained from the control. On the other hand, the interaction effect between added levels of phosphorus and zinc fertilizer in P content in the seed was found to be significant at ($P \leq 0.05$). The higher value of P content in the seed with giving (0.254 %) at (P1Zn2), compared to almost all other treatments. Moreover, significant differences were found from the interaction effect between phosphorus and zinc fertilizer in P content in the shoot, which was found to be significant at ($P \leq 0.05$), shown in Table 6. About the effect of applied phosphorus levels on P content in the shoot, the maximum mean value of P content in the shoot was (0.760%) observed with (P2). The minimum mean value of P content in the shoot was 0.662% observed with the control treatment. Other researchers have also reported P concentration [mg P (g DM) $^{-1}$] in whole safflower plants increased significantly with increasing P fertilization [37]. Relying on the effect of zinc fertilizer on P content in the shoot, the higher mean value of P content in the shoot was (0.775%) obtained at zinc level (Zn1) compared with (Zn2), which recorded (0.643%). In the present study, statistically significant differences were found between phosphorus and zinc fertilizer-level interactions in terms of P content in the shoot. The highest and lowest values for P content in the shoot were (0.877 and 0.573)%, which were recorded by (P2Zn1) and control, respectively.

Table (5): Effect of phosphorus, zinc, and their interactions on some nutrient content in the seed of safflower

Phosphorus Levels	Zinc Levels			Effect of Phosphorus
	Zn 0	Zn 1	Zn 2	
Phosphorus content in the seed %				
P 0	0.204 d	0.186 ef	0.228 bc	0.206 b
P 1	0.173 f	0.181 f	0.254 a	0.203 b
P 2	0.196 de	0.220 c	0.240 b	0.219 a
Effect of Zinc	0.191 b	0.196 b	0.241 a	
Zinc content in the seed mg kg^{-1}				
P 0	110.500 f	145.500 d	201.000 b	152.333 c
P 1	125.500 e	181.500 c	208.000 b	171.667 b
P 2	180.000 c	186.500 c	228.500 a	198.333 a
Effect of Zinc	138.667 c	171.167 b	212.500 a	
Iron content in the seed mg kg^{-1}				
P 0	196.000 e	200.000 de	225.000 cd	207.000 b
P 1	194.000 e	186.000 e	253.500 b	211.167 b
P 2	192.000 e	238.000 bc	288.000 a	239.333 a
Effect of Zinc	194.000 b	208.000 b	255.500 a	

Means within a column, row, and their interactions separately, followed with the same letters, are not significantly different according to Duncan's multiple range tests at ($p \leq 0.05$).

Zinc content in the seed and shoot

From Table 5, it appears that Zn content in the seed is highly and significantly influenced by application of phosphorus, zinc rates, fertilizer, and their interaction at ($P \leq 0.05$). The zinc content in the seed significantly increased with the application of phosphorus fertilizer levels to (P2). The maximum mean Zn content value was (198.333 mg kg^{-1}), obtained at (P2), which was significantly different compared with that obtained at the control level, which was (152.333 mg kg^{-1}).

Significant improvement in Zn content in the seed was also observed by application the zinc levels. The maximum mean value was (212.500 mg kg^{-1}), obtained at (Zn2), which was significantly different compared with that obtained at the control, which was (138.667 mg kg^{-1}). These findings were in agreement with those obtained by [38], who stated that Zn concentration in the seeds of safflower was increased by Zn application. Furthermore, [23] reported that the application of zinc enhanced zinc concentration in the seed of safflower. However, the interaction effect of phosphorus and zinc rates on Zn content in the seed was found to be significant. The highest value of Zn content in the seed was (228.500 mg kg^{-1}), recorded by (P2Zn2), while the lowest value was (110.500 mg kg^{-1}), and was recorded by the control.

Significant improvement in Zn content in the shoots was also observed by application the phosphorus and zinc rates of fertilizer in Table 6. The zinc content in the shoots significantly increased with the application of phosphorus levels. The maximum mean Zn content in the shoots value was (442.000 mg kg^{-1}), obtained at (P2), which significant difference when compared to the results obtained at the control level, which was (408.833 mg kg^{-1}). Concerning the effect of application of the zinc levels, the maximum mean value was (450.333 mg kg^{-1}), obtained at (Zn2), which was significantly different compared with that obtained at the control, which was (403.833 mg kg^{-1}) [35]. Also reported that zinc sulfate spraying leads to improved zinc concentration in stems and leaves of safflower compared with the control. Significant differences were found between phosphorus and zinc interaction on Zn content in the shoots. The maximum value of Zn content in the shoots was (479.500 mg kg^{-1}), recorded by (P2Zn2), while the minimum value was (376.500 mg kg^{-1}) recorded by the control.

Iron content in the seed and shoot

The result in Table 5 demonstrates that the phosphorus and zinc rates of fertilizer were significantly affected by the Fe content in the seed of the safflower plant at ($P \leq 0.05$). The Fe content in the seed significantly increased with increasing phosphorus rates. The maximum and minimum means of Fe content in the seed were (239.333 mg kg^{-1} and 207.000 mg kg^{-1}), recorded at treatment (P2) and control, respectively. Concerning the effect of zinc rate fertilizer on Fe content in the seed, significant differences were found at ($P \leq 0.05$). The highest mean Fe content in the seed (255.500 mg kg^{-1}) was obtained in treatment (Zn2), and the lowest mean Fe content in the seed (194.000 mg kg^{-1}) was obtained in the control. Similar to this study, in 2016, under regular irrigation conditions, the safflower crops that were sprayed with 7.5 g L^{-1} of zinc sulfate during the flowering stage exhibited the highest iron content in the seeds [39]. Depending on the effect of interaction between phosphorus and zinc rates at ($P \leq 0.05$). The maximum Fe content in the seed was (288.000 mg kg^{-1}), resulting from (P2Zn2), compared with (P1Zn1), which recorded (186.00 mg kg^{-1}).

Table (6): Effect of phosphorus, zinc, and their interactions on some nutrient content in the shoot of safflower

Phosphorus content in the shoot %				
Phosphorus Levels	**Zinc Levels**			**Effect of Phosphorus**
	Zn 0	**Zn 1**	**Zn 2**	
P 0	0.573 f	0.759 b	0.656 de	0.662 c
P 1	0.738 bc	0.689 cd	0.660 de	0.695 b

P 2	0.790 b	0.877 a	0.614 ef	0.760 a
Effect of Zinc	0.700 b	0.775 a	0.643 c	
Zinc content in the shoot mg kg^{-1}				
P 0	376.500 d	428.000 bc	422.000 c	408.833 b
P 1	405.000 c	407.500 c	449.500 b	420.667 b
P 2	430.000 bc	416.500 c	479.500 a	442.000 a
Effect of Zinc	403.833 b	417.333 b	450.333 a	
Iron content in the shoot mg kg^{-1}				
P 0	75.000 e	82.400 d	107.500 b	88.300 b
P 1	92.600 c	113.500 ab	119.000 a	108.367 a
P 2	88.500 c	119.000 a	108.500 b	105.333 a
Effect of Zinc	85.367 c	104.967 b	111. 667 a	

Means within a column, row, and their interactions separately, followed with the same letters, are not significantly different according to Duncan's multiple range tests at ($p \leq 0.05$).

Moreover, the result in Table 6 shows that the applied phosphorus rates significantly influenced the Fe content in the shoot. The maximum and minimum mean Fe content in the shoot were (108.367 mg kg^{-1} and 88.300 mg kg^{-1}), recorded at treatment (P1) and control, respectively. Concerning the effect of zinc rates on Fe content in the shoot, significant differences were found at ($P \leq 0.05$). The highest mean value of Fe content in the shoot was (111.667 mg kg^{-1}) obtained in treatment (Zn2), and the lowest mean Fe content in the shoot (85.367 mg kg^{-1}) was obtained in the control. Depending on the effect of interaction between phosphorus and zinc rates at ($P \leq 0.05$). The maximum Fe content in the shoot was (119.000 mg kg^{-1}), resulting from (P1Zn2 and P2Zn1), and the lowest Fe content in the shoot (75.000 mg kg^{-1}) was obtained in the control.

Effect of phosphorus, zinc fertilizer levels, and their interactions on the oil content in the seed and linoleic and linolenic acid in the seed oil of safflower plant

From the represented data in Table 7, it appears that significant differences were registered at ($P \leq 0.05$), for oil content in the seed % influenced by both applied levels of phosphorus and zinc fertilizer. Considering the effect of phosphorus, the maximum and minimum mean value of oil content in the seed were (35.804% and 34.046%), recorded from application of (P2 and P0) treatments, respectively. These results conform with the findings by [30]. When considering the effect of zinc, the highest significant mean value of oil content in the seed was (41.138%), which was recorded from application of (Zn2), while its lowest mean value was (29.016%), which was obtained from control. Zinc can increase fat metabolism and the way it affects the oil content [31]. On the other hand, the interaction effect between added levels of phosphorus and zinc fertilizer in oil content in the seed % was found to be significant at ($P \leq 0.05$). The higher value of oil content in the seed with giving (42.660%) at (P1Zn2), compared to almost all other treatments.

Table (7): Effect of phosphorus, zinc, and their interactions on the oil content in the seed and linoleic and linolenic acid in the seed oil of safflower

Oil content in the seed %				
Phosphorus Levels	Zinc Levels			
	Zn 0	Zn 1	Zn 2	Effect of Phosphorus
P 0	28.097 e	34.913 c	39.127 b	34.046 b
P 1	28.283 e	32.613 d	42.660 a	34.519 ab
P 2	30.667 d	35.120 c	41.627 a	35.804 a
Effect of Zinc	29.016 c	34.216 b	41.138 a	
Linoleic acid in the seed oil %				
P 0	63.267 c	64.720 ab	63.717 bc	63.901 b
P 1	63.063 c	65.620 a	63.637 bc	64.107 ab
P 2	64.530 ab	64.893 a	64.580 ab	64.668 a
Effect of Zinc	63.620 b	65.078 a	63.978 b	
Linolenic acid in the seed oil %				
P 0	0.073 d	0.090 ab	0.087 abc	0.083 a
P 1	0.077 cd	0.093 ab	0.083 bcd	0.084 a
P 2	0.073 d	0.097 a	0.087 abc	0.086 a
Effect of Zinc	0.074 c	0.093 a	0.086 b	

Means within a column, row, and their interactions separately, followed by the same letters, are not significantly different according to Duncan's multiple range tests at ($p \leq 0.05$).

Moreover, significant differences were found from the interaction effect between phosphorus and zinc fertilizer in linoleic acid in the seed oil percentage % which was found to be significant at ($P \leq 0.05$), shown in Table 7. Depending on the effect of applied phosphorus levels on linoleic acid in the seed oil, the maximum mean value was 64.668% observed with (P2), while the minimum mean value was 63.901% observed with the control treatment. The increase in linoleic acid due to the application of P has also been reported by [40] in safflower. Relying on the effect of zinc fertilizer on linoleic acid in the seed oil, the highest mean value was (65.078%) obtained at zinc-level (Zn1) compared with the control, which recorded (63.620%). [41] examined the effect of zinc sulfate ($ZnSO_4.7H_2O$) at (3000 mg L^{-1}) as a foliar application on safflower in 2002, and enhanced linoleic acid compared with the control. Concerning the interaction effect between both phosphorus and zinc fertilizer levels in linoleic acid in the seed oil %, significant differences were recorded due to these interactions.

From Table 7, it appears that linolenic acid in the seed oil % has no significant effect from the applied levels of phosphorus fertilizer; however, the applied levels of zinc fertilizer and the interaction between phosphorus and zinc fertilizers had a significant impact at ($P \leq 0.05$). Significant improvement in linolenic acid in the seed oil % was observed by application of the zinc levels. The maximum mean value was (0.093%), obtained at (Zn1), which was significantly different compared with that obtained at the control, which was (0.074%). The results are consistent with the findings of [42], who indicated that application of zinc improved linolenic acid in the seed oil of safflower when compared with the control. Moreover, the interaction effect of phosphorus and zinc rates on linolenic acid in the seed oil % was found to be significant. The maximum value was (0.097%), recorded by (P2Zn1), while the minimum value was (0.073%), which was recorded by (P2Zn0) and the control.

The results above indicate that the rates of phosphorus and zinc applied at levels of (P2Zn2 and P1Zn2) significantly influence the yield and yield components of the safflower plant, because phosphorus is necessary for the growth, development, and maturation of all crops. A sufficient supply of phosphorus during the early stages is essential for the initiation of their reproductive parts. Oilseeds and pulses require a lot of phosphorus due to its central role in plant metabolism [7]. Also, zinc is considered a micronutrient that has a prominent role in seed yield and plays an important role in the production of biomass. Furthermore, zinc may be required for chlorophyll production, pollen function, fertilization, and germination [43, 44].

From the results obtained in this study, it can be concluded that the interaction of different levels of phosphorus with zinc fertilizer to safflower plant enhanced growth, yield, and yield components characteristics, nutrients content in the rhizosphere soil, nutrients content in the seed and shoot of safflower plant that were taken in this present study. Additionally, the oil content in the seed (fatty acids such as linoleic and linolenic acid). The seed oil of the safflower plant was improved by fertilizing with the interaction of different levels of phosphorus and zinc. Finally, it could be concluded also both levels of (200 kg P_2O_5 ha^{-1} + 30 kg Zn ha^{-1} and 100 kg P_2O_5 ha^{-1} + 30 kg Zn ha^{-1}) had an impact on improving the yield and yield components of safflower**.**

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