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RESPONSE OF PEANUT TO WEED CONTROL MANAGEMENT AND NANO-ZINC FOLIAR APPLICATION IN GROWTH, YIELD, AND QUALITY TRAITS

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SUMMARY

A field experiment on a local peanut (*Arachis hypogaea* L.) cultivar transpired in the spring season of 2021 at the Al-Hussainiya region, Holy Kerbala, Iraq (Latitude: 32.6160; Longitude: 44.0249). The completed study aimed to determine peanut response to weed control, foliar application of nano-zinc, and their interaction in growth, yield, and quality traits. The experiment laid out in a split-plot design with two factors (weed control and nano-zinc foliar application) had three replications. The nano-zinc concentrations (0, 50, and 100 mg L^{-1}) occupied the main plots, with the weed control treatments kept in sub-plots. Weed control included the control (T_0 - no weed control), manual hoeing (T_1), and weed control with pre-emergence (pre-em) herbicides, i.e., Trifluralin (T_2) and Pendimethalin (T_3), and post-emergence (post-em) herbicides, viz., Oxyfluorfen (T_4) and Clethodim (T_5). The results showed that post-em herbicide Oxyfluorfen gave superior enhancement on the vegetative dry weight, pods per plant, seeds per plant, total pod yield, protein, and zinc in the seeds with increased values of 52.0%, 265.1%, 254.5%, 211.9%, 13.2%, and 25.5%, respectively, compared with the control treatment. Nano-zinc (100 mg L^{-1}) foliar application led to a significant increase in the above traits with increased rates of 2.5%, 21.2%, 40.6%, 7.4%, 8.2%, and 89.2%, respectively, compared with the control. The interaction between both factors showed significant superiority compared with no weeding and separate application of weed control combined with chemical herbicides and nano-zinc application. The interaction between the post-em weed management (Oxyfluorfen) and nano-zinc (100 mg L^{-1}) application showed highly superior compared with other treatments in the studied traits.

Keywords: *Arachis hypogaea* L., nano-zinc foliar, manual and chemical weed control, herbicides, trifluralin, pendimethalin, oxyfluorfen, clethodim, protein and zinc content, growth and yield traits

Key findings: Peanut traits gained a significant and sustainable improvement in growth, yield, and quality from the post-em (Oxyfluorfen) weed management and nano-zinc (100 mg L^{-1}) foliar application.

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INTRODUCTION

Peanut (*Arachis hypogaea* L.), one of the crops of substantial economic and high nutritional values globally, belongs to the family Leguminosae. Its seeds contain oil (45%–50%) and protein (27%–33%) and are essential sources of minerals and vitamins (El-Naim *et al*., 2011; Ali *et al*., 2022). Iraq consumes large quantities of this crop, more than 40,000

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t annually, often for oil extraction. The hope to increase the cultivated area of this crop in Iraq remains due to the increasing demand for its multiple industrial uses (Al-Kaisy and Al-Saad, 2010).

Low peanut crop productivity may come from the competition with weed plants, which reduces crop growth, especially in the early stages, and pod output. Various species of weeds have been identified in Iraqi peanut farms, affecting the crop. Among weeds, the majority of them are narrow leaves, such as, nutgrass (*Cyperus rotundus* L.), barley grass (*Imperata cylindrical* L.), broad leaf rough pigweed (*Amaranthus retroflexus* L.), field bindweed (*Convolvulus arvensis* L.), and purslane (*Portulaca oleracea* L.) (Soltani *et al*., 2013). Chemical weed control through herbicides emerged as an alternative to manual weed control and hoeing, with reports as effective means to combat the weed flora in various crops (Priya *et al*., 2017). Grichar and Dotray (2007) indicated that herbicide use controls and reduces weed density during the early stages of the plant's life, thus allowing many crops, including field peanuts and other crops, to grow well. Qasem’s (2011) findings indicated that the increase in the effectiveness of weed repellants depends on the density of the weed and the extent of the resistance of this weed to the herbicides, which determines whether the weed control process is completely effective compared with the manual control of these.

Many current studies indicated that adding fertilizers through the soil may be insufficient for plants to obtain the nutrients, whether macro or micro-elements. In modern crop fertilization techniques, foliar feeding takes a wide range of researchers' attention. Therefore, the foliar application of plant nutrients, especially micro-nutrients, has become an effective way to increase production and improve the quality of field crops (Talebbeigi *et al*., 2018).

Although requiring only a tiny amount, micronutrients are highly effective because of the growth they promote and their ability to modify equilibrium inside the plant, which then boosts the activity of enzymes necessary for a wide range of biological activities (Brown *et al*., 2022) The leaves play a critical role as the site of several critical processes, including photosynthesis, transpiration, and the absorption of mineral nutrients through the stomata on the upper and lower surfaces of the leaves. Foliar applications of micronutrients provide plants with the nutrients needed by crop plants (Bameri *et al*., 2012).

Through the cuticle layer, which is partially permeable to water and solutions, the importance and role of the leaves are equal to the roots in terms of the ability to absorb, transport, and distribute nutrients in the crop plants. Nandi’s *et al*. (2020) findings revealed that foliar application of zinc on the field peanut plants led to an increase in the leaf area at the flowering and pod formation stages. Zinc alone led to an increase in the chlorophyll content in the leaves, which eventually increased the yield of field peanut plants.

With nanotechnology, agriculture has seen a dramatic transformation. New techniques development increased plant uptake of nutrients and fertilizers (Neme *et al*., 2021). Hence, the efficient use of nanotechnology enables the development of ways to find solutions and treatments for many agricultural problems. Zinc is one of the micronutrients that mainly determine plant growth and the quality of the product in terms of nutrition, despite the small quantities that crops need of zinc compared with the macronutrients. The availability of different mineral and chelating fertilizer sources for these nutrients and the various application methods can easily add to the soil, sprinkled on the leaves, or both. The efficient use of these fertilizers lessened. Thus recently, a trend to use micro-nutrients manufactured with nanotechnologies began, with hopes of solving part of the problem, but the subject requires more study (Ali and Al-Juthery, 2017).

Foliar application of nano-zinc at the seed-filling stage led to a significant increase in the pod yield and seeds for field pistachio plants, with an increase of 37.8% and 27.5%, respectively, compared with the control treatment (Liu and Lal, 2015). Past findings revealed that the spraying with nano-zinc led to increased pod yield and seeds and improved their nutritional values (Malandrakis *et al*., 2019). These results might be due to the beneficial effects of zinc on metabolic processes and growth, which in turn reflected positively in the chemical content of field peanut seeds.

The need to study weed control and spraying with nano-zinc and their impact on developing agricultural techniques and increasing production in quantity and quality of field peanut plants requires urgency. Therefore, the latest study aimed to evaluate the efficiency of the weed herbicides (Trifluralin, Pendimethalin, Oxyfluorfen, and Clethodim) to destroy different weed types harming the field peanut crop and to determine

Table 1. Chemical and physical properties of the study soil at a depth of 0–30 cm before peanut planting.

Properties		Values
pH		7.8
EC (1:1)		2.81 ds m^{-1}
OM		1.34 g kg^{-1}
N available		30.44 mg kg^{-1}
K available		28.27 mg kg^{-1}
P available		11.2 mg kg^{-1}
Soil separators	Sand	250 G kg^{-1}
	Silt	360 G kg^{-1}
	Clay	390 G kg^{-1}
Texture		Clay loam

Table 2. Scientific names of the herbicides, the active substance, and the concentration used.

Trade name	Active substance	Used concentration	Origin
Trifloyam EC	Trifluralin 44.5%	2.4 L ha^{-1}	Yamama Agricultural Company
Trinity EC	Pendimethalin 33%	2.0 L ha^{-1}	Parijat Company of India
Toure EC	Oxyfluorfen 24%	1.0 L ha^{-1}	Lineco Company of Spain
Select Super EC	Clethodim 120g/ L	1.0 L ha^{-1}	Arysta Life Science Corporation

the best concentration for foliar application of nano-zinc to increase the production quantitatively and qualitatively.

MATERIALS AND METHODS

Experimental procedure and crop farming

A field experiment on a local peanut cultivar materialized in the spring season of 2021 in the Al-Hussainiya region, Holy Karbala, Iraq, on clay loam texture soil (Table 1). The present study aimed to determine peanut response to weed control, foliar application of nano-zinc, and their interaction in growth, yield, and quality traits. The experiment, laid out in a split-plot design, consisted of two factors (weed control and nano-zinc foliar application) and three replications.

The soil field preparation for cultivation included plowing, smoothing, and leveling operations, with the local peanut cultivar's seeds sown in rows, at 75 cm space between rows and a 30 cm space between seeds, on 12 April 2021. Planting followed on one side of the meadow and across three meadows, with two to three seeds sown in each hole at a depth of 3–5 cm to achieve a plant density of 44400 plants ha^{-1} (Al-Hilfy and Al-Muger, 2016). The nano-zinc concentrations (0, 50, and 100 mg L^{-1}) occupied the main plots, sprayed in two stages, i.e., a) at the beginning of flower formation and b) at the time when the spurs penetrate the soil or at the beginning of pod formation, while weed control treatments remained in sub-plots. Weed control included the control (T_0 - no weed control), manual hoeing (T_1), and weed control with pre-em herbicides, i.e., Trifluralin 48% EC (T_2) and Pendimethalin 33% EC (T_3), and post-em herbicides, viz., Oxyfluorfen 24% (T_4) and Clethodim (T_5) (Table 2).

The foliar application used a 16-liter dorsal sprayer and a diffuser, such as, bubblegum, adding in an amount of 0.16 ml L^{-1} to break the superficial tension layer of the plant leaves because of a waxy layer covering the stomata. Herbicide spraying ensued in the early morning according to the recommendations and procedures. Per the established safety protocol, the thinning process followed after the plant reached a height of 20–25 cm, with the incubation or export process taking place. It is the collection of soil around the plant so that the spurs arising after flowering time could penetrate the soil and ensure soil moisture preservation, increasing the yield.

According to the fertilizer recommendation 100:80:160 kg NPK ha^{-1}, mineral fertilizers given to the experimental field went by feeding method at a depth of 5 cm. These fertilizers provided nitrogen (46% N), phosphorus (19% P_2O_5), and potassium (50% K_2O) to the soil. The first application occurred two weeks after planting, adding some phosphate fertilizer to encourage the growth of root nodes (rhizobium). The second at the beginning of flowering and spike formation, giving some equal parts nitrogen and potassium fertilizer (Mullins and Hansen, 2006) and irrigating whenever needed.

Data recorded

In each experimental unit for dry weight of the plant, drying the vegetative parts of the plants of each treatment used an electric oven at a temperature of 105 °C for 2 h, then at a temperature of 60 °C for 48 h (Chemists and Horwitz, 1990). For the number of pods per plant^{-1}, the total number of pods for five randomly selected plants was calculated, with the average number of pods per plant extracted. The number of seeds per pod^{-1} had all seeds counted from the sample after peeling, with the average number of seeds per plant^{-1} extracted. For pod yield (t ha^{-1}), after separating the pods of the five taken plants and cleaning them from dust, their weights were taken, then dried in the oven at 65 °C until the weight was stable. Afterward, calculating the yield of pods proceeded for five plants (g plant^{-1}), with the yield of pods converted to kg ha^{-1} through plant density (44400 plant ha^{-1}) and the weight adjusted to the humidity of 8% using the following equation (Cross, 1980).

$$Total\ pods\ yield\ = average\ yield\ per\ plant\ \times\ plant\ density$$

For protein % in the peanut seeds, the nitrogen estimation used the Microkieldahl device, from which the protein percentage calculation followed the equation below (Chemists and Horwitz, 1990).

$$Protein\ content\ (\%)\ = aSeed\ nitrogen\ content\ (\%)\ \times\ 6.25$$

For zinc content in the peanut seeds, zinc determination used an atomic absorber (Haynes, 1980).

Statistical analysis

Results of the data collected from the field experiment underwent statistical analysis according to the analysis of variance (ANOVA) as per the split-plot design (Gomez and Gomez, 1984). The least significant difference ($LSD_{0.05}$) test used to compare and separate the mean differences employed the statistics software GenStat12.

RESULTS

According to the analysis of variance, the weeds control measures, nano-zinc concentrations, and interactions of weeds control × nano-zinc revealed significant ($P \leq 0.05$) differences for most traits (Table 3).

Table 3. Analysis of variance with two factors (weeds control measures and nano-zinc application), and their interaction for various traits in peanuts.

Source of variation	d.f.	Mean squares					
		Dry plant weight (g plant^{-1})	Pods per plant^{-1}	Seeds per plant^{-1}	Pod yield (t ha^{-1})	Protein in seeds (%)	Zinc in seeds (mg g^{-1})
Replications	2	9.22	1.269	2.272	5.090	5.162	10.26
Nano-zinc	2	370.05*	74.676*	348.725*	5.842*	36.216*	12551.17*
Weeds control	5	10327.93*	675.321*	1034.289*	3.581*	13.899*	682.96*
Nano-zinc × Weeds control	10	892.45*	104.418	183.148*	2.612*	12.225*	864.57*
Error B	30	14.05	3.466	5.749	9.364	1.514	16.85

The dry weight of the plant

The results indicated significant differences among the average values of the various treatments for the dry weight of the plant (Table 4). The manual hoeing treatment (weed-free) and the treatments of chemical weed management showed significantly superior over the control treatment (no weed control). The manual hoeing provided the maximum dry weight of the plant (157.9 g plant^{-1}), followed by Trifluralin (74.4 g plant^{-1}), Pendimethalin (73.8 g plant^{-1}), Oxyfluorfen (102.1 g plant^{-1}), and Clethodim (76.5 g plant^{-1}). However, Oxyfluorfen (post-em) significantly outperformed the other weed killers, i.e., Trifluralin, Pendimethalin, and Clethodim, with an increase of 37.23%, 38.34%, and 33.46%, respectively. The results also revealed the significant superiority of foliar application of nano-zinc at a concentration of 100 mg L^{-1} with the highest mean value for dry weight of the plant (97.15 g plant^{-1}), compared with the control (85.78 g plant^{-1}) and nano-zinc spraying at a concentration of 50 mg L^{-1} (87.15 g plant^{-1}).

The interaction between the two factors of the study showed significant differences in the dry weight of the plant (Table 4). As a result of the weed management

Table 4. Effect of weed control measures and nano-zinc concentrations on the dry weight of plant (g plant^{-1}).

Weeds control measures	Nano-zinc concentrations (mg L^{-1})			Means
	F_0	F_1	F_2	
Control (T_0)	45.0	43.7	58.2	48.96
Weed-free (T_1)	144.4	152.7	176.6	157.9
Trifluralin (T_2)	87.8	65.7	69.8	74.4
Pendimethalin (T_3)	53.3	81.4	86.7	73.8
Oxyfluorfen (T_4)	98.2	98.5	109.6	102.1
Clethodim (T_5)	86	81.6	82.0	76.5
Means	85.78	87.15	97.15	

$LSD_{0.05}$ Nano-Zinc concentrations = 1.78, $LSD_{0.05}$ Weeds Control = 3.31, $LSD_{0.05}$ WC × NZ Interactions = 4.65

Table 5. Effect of weed control measures and nano-zinc concentrations on the number of pods per plant^{-1}.

Weeds control measures	Nano-zinc concentrations (mg L^{-1})			Means
	F_0	F_1	F_2	
Control (T_0)	9.8	7.1	9.0	8.6
Weed-free (T_1)	19.2	31.4	30.2	26.9
Trifluralin (T_2)	22.4	21.0	20.1	21.1
Pendimethalin (T_3)	8.4	16.4	14.5	13.1
Oxyfluorfen (T_4)	27.4	23.2	43.6	31.4
Clethodim (T_5)	20.2	13.0	13.2	15.4
Means	17.9	18.6	21.7	

$LSD_{0.05}$ Nano-Zinc concentrations = 1.892 , $LSD_{0.05}$ Weeds Control = 1.273, $LSD_{0.05}$ WC × NZ Interactions = 3.044

and foliar application of nano-zinc, the interaction of manual hoeing and nano-zinc at a concentration of 100 mg L^{-1} significantly outperformed (176.6 g plant^{-1}) all other interaction treatments, followed by weed-free (T_1) treatment and nano-zinc at a concentration of 50 mg L^{-1}, at 152.7 g plant^{-1} compared with other interaction treatments between the herbicides, viz., Trifluralin, Pendimethalin, Clethodim, and nano-zinc foliar application. Still, the control treatment revealed the lowest value for the dry weight of the plant (45.0 g plant^{-1}).

Pods per plant

The results indicated that the post-em herbicide Oxyfluorfen displayed superiority in producing more pods per plant (31.4 pods plant^{-1}) than all other weed control treatments (Table 5). The chemical weed control treatments (pre- and post-em) recorded the highest average increase of 265.11%, 16.72%, 48.81%, 139.69%, and 103.89% compared with the control treatment (no weeding), hand hoeing (T_1) and Trifluralin, Pendimethalin, and Clethodim treatments, respectively. The manual hoeing - weed-free (26.9 pods^{-1}) followed, showing significantly superior to the rest of the treatments. The pre-em herbicides, viz., Trifluralinn and Pendimethalin, gave 21.1 and 13.1 pods plant^{-1}, respectively, while the post-em herbicide Clethodim resulted in 15.4 pods plant^{-1}. Further results showed the significant effect of foliar application of nano-zinc at a concentration of 100 mg L^{-1} giving the highest average value (21.7 pods plant^{-1}) compared with the treatment of no weed control and foliar application of nano-zinc at a concentration of 50 mg L^{-1}. The latter two recorded with 17.9 and 18.6 pods plant^{-1} with an increase of 21.22% and 16.66%, respectively.

The interaction between both factors of the study showed significant differences with the various weed control measures and nano-zinc foliar application with different concentrations (Table 5). The interaction treatment comprising post-em herbicide Oxyfluorfen and nano-zinc application at a concentration of 100 mg L^{-1} outperformed significantly (43.6 pods plant^{-1} with an increase of 344.89%) all other treatments and control with no weed control and no zinc application (9.8 pods plant^{-1}). Following the above promising interaction was the interaction of manual hoeing and nano-zinc at a concentration of 100 mg L^{-1}), which amounted to 31.4 pods plant^{-1}, significantly excelling the rest of the treatments with an increase of 208.16% compared with the control treatment.

Seeds per plant

The results indicated that post-em herbicide Oxyfluorfen significantly excelled all treatment averages, with the highest recorded average of 39.0 seeds plant^{-1} and an increase of 254.5% compared with the control treatment (11.0 seeds plant^{-1}) (Table 6). The manual hoeing treatment (36.9 seeds plant^{-1}) followed, showing significant superiority to the rest of the treatments. The pre-sowing herbicides Trifluralinn and Pendimethalin produced 25.6 and 21.3 seeds plant^{-1}, respectively, while the post-em herbicide Clethodim gave 19.6 seeds plant^{-1}. The results also showed the significant effect of nano-zinc foliar application at a concentration of 100 mg L^{-1}, providing the highest average of 30.1 seeds plant^{-1}, followed by the control treatment (21.4 seeds plant^{-1}) and nano-zinc at the rate of 50 mg L^{-1} (25.2 seeds plant^{-1}), with an increase of 40.6% and 19.4%, respectively.

The interaction of both factors showed significant differences between weed control treatments and foliar application of nano-zinc (Table 6). The interaction of post-em herbicide Oxyfluorfen with foliar application of nano-zinc at a concentration of 100 mg L^{-1} significantly exhibited superiority (52.3 seeds plant^{-1}), with an increase of 308.59% compared with the control treatment (no weed control + no Zn application), which amounted to 12.8 seeds plant^{-1}. The above promising combination has the interaction between manual hoeing and spraying with nano-zinc at a concentration of 100 mg L^{-1} (45.0 seeds plant^{-1}) as the second, significantly outperforming the rest of the treatments with an increased rate (251.56%) compared with the control treatment.

Table 6. Effect of weed control measures and nano-zinc concentrations on the number of seeds per plant^{-1}.

Weeds control measures	Nano-zinc concentrations (mg L^{-1})			Means
	F_0	F_1	F_2	
Control (T_0)	12.8	10.2	10.2	11.0
Weed-free (T_1)	23.6	42.3	45.0	36.9
Trifluralin (T_2)	24.7	25.2	26.9	25.6
Pendimethalin (T_3)	8.4	26.4	29.2	21.3
Oxyfluorfen (T_4)	34.6	30.2	52.3	39.0
Clethodim (T_5)	24.4	17.0	17.5	19.6
Means	21.4	25.2	30.1	

$LSD_{0.05}$ Nano-Zinc concentrations = 2.273, $LSD_{0.05}$ Weeds Control = 1.657, $LSD_{0.05}$ WC × NZ Interactions = 3.865

Table 7. Effect of weed control measures and nano-zinc concentrations on the pod yield (t ha^{-1}).

Weeds control measures	Nano-zinc concentrations (mg L^{-1})			Means
	F_0	F_1	F_2	
Control (T_0)	0.668	0.539	0.569	0.592
Weed-free (T_1)	2.240	2.276	2.331	2.282
Trifluralin (T_2)	1.642	1.307	1.422	1.457
Pendimethalin (T_3)	0.442	1.395	1.003	0.946
Oxyfluorfen (T_4)	1.733	1.520	2.288	1.847
Clethodim (T_5)	1.208	0.882	0.909	0.999
Means	1.322	1.319	1.420	

$LSD_{0.05}$ Nano-Zinc concentrations = 0.008, $LSD_{0.05}$ Weeds Control = 0.009, $LSD_{0.05}$ WC × NZ Interactions = 0.016

Pod yield

The various weed control measures indicated significant differences in peanut pod yield (Table 7). The manual hoeing led all treatments by producing the pods of 2.282 *M*g ha^{-1}, revealing superiority to all other treatments in terms of the total pod yield, followed by the pre-em herbicide Oxyfluorfen (1.847 *M*g ha^{-1}). Moreover, the herbicide Oxyfluorfen displayed significant superiority to the other three herbicides, i.e., Trifluralin (1.457 *M*g ha^{-1}), Pendimethalin (0.946 *M*g ha^{-1}), and Clethodim (0.999 *M*g ha^{-1}), with an increase of 26.76%, 95.24%, and 84.88%, respectively. The results also showed the significant effect of foliar application of nano-zinc at a concentration of 100 mg L^{-1} by giving the highest average pod yield (1.420 *M*g ha^{-1}) compared with the no weed control and nano-zinc (50 mg L^{-1}), recorded with 1.322 and 1.319 *M*g ha^{-1}, respectively.

The interaction of both factors showed significant differences as a result of the weed control treatments and nano-zinc foliar application (Table 7). The interaction between manual hoeing and spraying with nano-zinc at a concentration of 100 mg L^{-1} provided the pod yield of 2.331 *M*g ha^{-1} significantly surpassed all treatments, , followed by the interaction between the pre-em herbicide Oxyfluorfen and nano-zinc foliar application at a concentration of 100 mg L^{-1} (2.288 *M*g ha^{-1}).

Protein % in the seeds

The results indicated that weed management with post- and pre-em herbicides, viz., Oxyfluorfen, Pendimethalin, and Trifluralin, and hand hoeing displayed significant superiority at 29.9%, 29.7%, 29.0%, and 29.0%, respectively, in protein content of the peanut seeds (Table 8). No significant difference occurred between protein means of post-em herbicide Clethodim (28.2%) and control treatment (26.4%). The results also enunciated the highest average protein content (30.3%) as the significant effect of foliar application of nano-zinc at a concentration of 100 mg L^{-1} for protein %, compared with no Zn application (28.0%) and nano-zinc at a concentration of 50 mg L^{-1} (27.8%), with an increase of 8.21% and 8.99%, respectively, in protein content of the peanut seeds.

The interaction between both factors of the study showed significant differences among the weed control treatments and nano-zinc foliar application for protein content in peanut seeds (Table 8). The interaction of pre-em herbicide Pendimethalin and manual hoeing with the nano-zinc foliar application (100 mg L^{-1}) provided the highest percentage of protein, i.e., 32.8% and 32.7%, respectively, significantly surpassing all treatments, with an increase of 26.64% and 26.25% compared with control (no weed control + no Zn). Following the above promising interactions were an interaction of post-em herbicide Oxyfluorfen and nano-zinc application at a concentration of 50 mg L^{-1} (31.5%), with an increase of 21.62% in protein content compared with the control treatment. However, no significant differences existed among the above three promising interactions for protein content in peanut seeds, but they still gave considerable superiority to the rest of the interactions.

Table 8. Effect of weed control measures and nano-zinc concentrations on the protein (%) in the seeds.

Weeds control measures	Nano-zinc concentrations (mg L^{-1})			Means
	F_0	F_1	F_2	
Control (T_0)	25.9	24.2	29.3	26.4
Weed-free (T_1)	29.4	24.9	32.7	29.0
Trifluralin (T_2)	28.9	29.4	28.8	29.0
Pendimethalin (T_3)	27.8	28.6	32.8	29.7
Oxyfluorfen (T_4)	29.0	31.5	29.4	29.9
Clethodim (T_5)	27.0	28.4	29.3	28.2
Means	28.0	27.8	30.3	

$LSD_{0.05}$ Nano-Zinc concentrations = 0.91, $LSD_{0.05}$ Weeds Control = 0.92, $LSD_{0.05}$ WC × NZ Interactions = 2.01

Zinc content in seeds

Significant differences emerged among the weed control treatments for average values of zinc content in peanut seeds (Table 9). The post-em herbicide Oxyfluorfen treatment (97.4 mg g^{-1}) showed significant superiority to all the treatments at an increase of 25.51% in zinc content compared with the control treatment (77.6 mg g^{-1}). The promising treatment had the pre-em herbicides Trifluralinn (89.7 mg g^{-1}) and Pendimethalin (93.9 mg g^{-1}) as second best. However, the post-em herbicide Clethodim gave the lowest zinc content at 80.7 mg g^{-1}. The results also revealed a significant effect of foliar application of nano-zinc at a concentration of 100 mg L^{-1} with the highest average zinc content (113.0 mg g^{-1}) compared with the control treatment (59.0%) and nano-zinc at a concentration of 50 mg L^{-1} (85.9%), with an increase of 89.27% and 31.54%, respectively in zinc content of the peanut seeds.

The interaction between weed control measures and nano-zinc foliar application revealed a significant effect on zinc content in peanut seeds (Table 9). The interaction of nano-zinc foliar application (100 mg L^{-1}) with

Table 9. Effect of weed control measures and nano-zinc concentrations on the zinc content in seeds (mg kg^{-1}).

Weeds control measures	Nano-zinc concentrations (mg L^{-1})			Means
	F_0	F_1	F_2	
Control (T_0)	65.1	72.0	95.8	77.6
Weed-free (T_1)	40.3	74.2	119.3	77.9
Trifluralin (T_2)	70.1	73.2	125.9	89.7
Pendimethalin (T_3)	67.8	88.2	125.7	93.9
Oxyfluorfen (T_4)	84.1	105.1	103.1	97.4
Clethodim (T_5)	30.8	102.8	108.5	80.7
Means	59.7	85.9	113.0	

$LSD_{0.05}$ Nano-Zinc concentrations = 5.16, $LSD_{0.05}$ Weeds Control = 2.46, $LSD_{0.05}$ WC × NZ Interactions = 6.81

pre-em herbicides Trifluralin and Pendimethalin and manual hoeing showed a significant increase in zinc content (125.9, 125.7, and 119.3 mg g^{-1}), respectively, with percent values at 93.3%, 93.0%, and 83.25%, respectively, compared with the control having the lowest value of zinc content in peanut seeds (65.1 mg L^{-1}).

DISCUSSION

Results authenticated the importance of weed control measures and foliar application of nano-zinc in increasing plant growth, yield, and quality traits in field peanuts, especially post-em foliar application of herbicide Oxyfluorfen. It stopped cell membrane growth since the herbicide Oxyfluorfen used the light to increase its activity by inhibiting and stopping both electron transfer and ATP synthesis, reducing the weed's competition for the crop and allowing better growth, causing an increase in the dry weight of the vegetative parts of the crop plants (Janaki *et al*., 2013). Given the herbicide Oxyfluorfen's effects on unstable carotenoids that stimulate the formation of free radicals, which in turn easily interact with membrane lipids to give additional poor substances that make the weed's growth abnormal and thus weaken the weed's competition in the different stages of plant growth (Solanki *et al*., 2005).

The efficient carbonization process, improving the biological efficiency of the crop, and increasing vegetative growth directly caused an increase in the number of pods per plant in groundnut (Kalhapure, 2013). As a result of the effect of herbicides, especially Oxyfluorfen, on harmful weeds in the early and critical stages of the plant's life provided a suitable environment for the growth and development of the plant, thus reducing competition between the weeds and their occurrence in plants' early stages, especially with the herbicide use after planting, increasing the number of seeds per plant in peanuts (Solanki *et al*., 2005). The superiority of Oxyfluorfen after planting, which has a significant effect on the yield of field peanuts, came from a reduction in the density of the growing weeds during the growth period of field peanuts and during the period of pods formation in groundnut (Ramalingam *et al*., 2013). Furthermore, the herbicidal effect on the cell membrane caused disruption of the cells, ionic balance, and ultimately death of the weeds (Rao, 2000).

Nano-zinc foliar application also depends on the size of nanoparticles, as these particles can enter the plant tissues, such as, stomata and wood, by increasing their concentration in the spray solution. Moreover, zinc is slow to move inside the plant, so its accumulation increases in the vegetative and root system, promoting the production of more plant cells and processed materials for further storage in the different parts of the crop plants (Pandey, 2018). Zinc is an activator of various enzymes in plants that directly enter into the biosynthesis of growth materials, such as, natural growth regulators indole acetic acid (IAA***)*** that promotes the production of more plant cells and biomass stored in plant parts, such as seeds. Zinc also plays a vital role in essential activities, such as carbon metabolism and respiration, and energy production; it increases the efficiency of nutrient absorption, enhancing crop growth and the nutritional content in the parts, promoting the significant increase in the number of pods and seeds in the plant (Malandrakis *et al.*, 2019; Alamery and Ahmed, 2020).

The result of effectively controlling the growth of the weeds by using herbicide before and after planting, as the weeds harm the yield and its components through the high competition of the weeds for water and nutrients in the soil was positively reflected in the availability of nitrogen for the plant and the production of plant hormones, which leads to an increased division of meristem cells. A positive reflection reveals in the size of the vegetative and root system and the formation of flowers and then the increase in chlorophyll content, hence raising the efficiency of the carbon metabolism process and increasing its products and its transmission from the source to the estuary in the groundnut (Sharma *et al*., 2015).

Plants uptake the nitrogen and mix it with carbohydrates to make amino acids, linking together to generate proteins. The proportion of crude protein is the most important, with substantial determination by the amount of nitrogen supplied during its creation. The length of the seed-filling period can be attributed, in part, to the availability of nitrogen during the different stages of growth, which plays an essential role in the synthesis of amino acids and the storage of proteins in the vegetative tissues (Uchida, 2000). Zinc contributes to the formation and assimilation of protein, as well as, in nitrogen transformations (Narimani *et al*., 2010), playing a crucial role in forming the amino acid tryptophan, from where the hormone IAA results, which is necessary for the elongation of the stem and cells in general.

Zinc also helps in the formation of chlorophyll as a result of its direct effect on the processes of formation of amino acids, carbohydrates, and energy compounds, contributing to cell division, pollen grains, and secondary meristem cell formation, and increasing the thickness of cells (Brennan, 2005; Alloway, 2008). The increase in the zinc content in the seeds may come from the lack of competition from the weeds to the plant, probably resulting from the effects of herbicides allowing the plant to intercept and absorb light, increasing the efficiency of growth and absorption of nutrients. Effectively increasing the growth and activity of plants through the reaction of enzymes necessary for various vital processes affects the content of chlorophyll in leaves and increases the leaf area, positively reflecting an increase in the products of the carbonization process to be transmitted to the seeds during their emergence (Ramalingam *et al*., 2013).

The increase in zinc content in the seeds may be due to the plant's necessary need for it in the formation of the amino acid, which forms the growth regulators for entering the process of phosphorylation and the formation of glucose sugar as it acts as a starch representation (Asl *et al*., 2019). The nano-fertilizers used as a source of zinc consisted of features that make them more efficient by increasing the absorption surface, which leads to a higher carbon metabolism process and thus increases the production of active substances in the plant, which eventually enhances the zinc content in the seeds (Yang *et al*., 2016). It is consistent with the findings of Al-Yasari and Al-Hilli (2018, 2019) and Al-Yasari (2022) that nano-fertilizers foliar application increased the growth, productivity, and quality of the various crop plants. The interaction of both factors (weed control with herbicides and nano-zinc application) displayed a significant effect that increased most of the studied traits, showing a positive impact in obtaining higher peanut production. Increased production in terms of quantity and quality per unit area reflects well on the economic return of the farmer by reducing costs and achieving economic benefits.

CONCLUSIONS

The gathered results enabled the conclusion that weed control with the pre-em application of oxyfluorfen revealed more effective in controlling weeds and enhancing peanut productivity resulting in higher economic returns. Nano-zinc foliar application increases vegetative growth, enhances photosynthesis, and thus improves the composition of crop components, leading to an enhanced pod yield and improvement in peanut quality. The interaction between herbicide Oxyfluorfen and nano-zinc (100 mg L^{-1}) proved the best responsive in improving the growth, pod yield, and quality of peanuts.

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