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Effect of nano NPK fertilizer and amino acids (Tecamin Max) as foliar application on vegetative growth, yield and leaf mineral content of two potato cultivars (*Solanum tuberosum* L.)

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Abstract

A field experiment was performed at Dinaran village, Bardarash district, Duhok governorate, Kurdistan region-Iraq during the spring season of 2024 aiming to study the impact of three levels of nano NPK fertilizer (0, 2 and 4 g L^{-1}) and three levels of Tecamin Max (0, 3 and 6 mL L^{-1}) as foliar application on vegetative growth, yield traits and mineral content in leaves of two potato cultivars (Harry and Lucinda). The experiment was laid out in a split-split plot design with three replications, following the principles of a randomized complete block design (RCBD). The results showed that the Harry cultivar was better than Lucinda cultivar in chlorophyll content (44.36) SPAD units, leaf nitrogen content (2.25 %), plant yield (1.309 kg $plant^{-1}$) and total yield (58.18 t ha^{-1}). However, no significant differences were observed between cultivars in the number of aerial stems, phosphorus, and potassium content in leaves. Application of nano NPK at 4 g L^{-1}, significantly enhanced all evaluated parameters relative to lower concentrations. Foliar application of Tecamin Max at 3 mL L^{-1} significantly increased the number of aerial stems (4.22 stem $plant^{-1}$), plant yield (1.372 kg $plant^{-1}$), and total yield (60.98) t ha^{-1}, whereas the 6 mL L^{-1} dose resulted in significantly higher leaf mineral content and chlorophyll SPAD values. The dual and triple combination treatments among cultivars, nano NPK fertilizer and Tecamin Max, resulted in the highest values for most of the studied parameters of potato plants.

Key words: Potato, cultivars, nano NPK, Tecamin Max, foliar application, growth, leaf mineral content, yields

Introduction

The potato (*Solanum tuberosum* L.) is one of the major vegetable crops in numerous countries worldwide, including Iraq, which is a member of the Solanaceae family. It is grown extensively in Iraq and many other places of the globe due to its premium economic prestige, which is considered a strategic crop with high popularity. The mass production of the potato crop in Iraq is estimated to be about 270,591 tons, with an area of 12645 hectares devoted to its cultivation and a maximum harvest income of 21399.2 kg ha^{-1} (CSO, 2022).

The successful cultivation of different potato cultivars depends essentially on the genotype-environment interaction, which may affect tuber yield as well as quantitative and qualitative characters. AL-Bayati *et al.* (2020) mentioned that the Arizona cultivar surpassed the potentials of both Sylvana and Volar cultivars in terms of the number, average weight, and harvest yield of tubers as well as total yield. The number of tubers per hill was much higher in cultivar Florice, but the percentage of dry matter, starch content and specific gravity of tubers were significantly more in Montreal (Al-Sultan *et al.* 2023).

Potato can deplete large quantities of primary nutrient elements (NPK) from the soil as they continue growing to attain maximal harvest of tubers and premier quality. Therefore, researchers around the world have targeted the study of some modern technologies in the agricultural system, including the probable utilization of nanotechnology to raise the efficient use of fertilizers towards the design and development of what is known as nano-fertilizers (Elemike *et al.* 2019).

Nano fertilizers are considered to have better effectiveness and efficiency than conventional fertilizers due to their beneficial influences on the nourishment quality of crops and their capability of reducing different stresses on plants in addition to their cost-effectiveness since low amounts are added. Furthermore, they are taken up rapidly by the roots and easily penetrate cells and are transported and represented within the plant tissues (Warheel *et al.* 2025). Abd El-Aziem *et al.* (2020) demonstrated that adding 50% of the recommended chemical fertilizer with nano-fertilizer sprays for potato plants resulted in a remarkable enhancement in foliage and yield parameters.

Recently, the world has paid extra attention to the utilization of organic inputs as fertilizers in an attempt to decrease environmental contamination and its bad consequences on human health via minimizing the application of inorganic fertilizers and chemicals in crop production, particularly those which are consumed fresh and instead, the natural alternatives were used (Kahlel and Sultan 2019; Taha *et al*., 2025). Tecamin Max plays a great role in several physiological and biological processes in plants and the plants require such Tecamin Max for sustained growth and productivity. Tecamin Max is recognized as a modern means to be sprayed on the plant, where it can improve agricultural productivity.

Al-Hamdani *et al.* (2017) concluded that treating the potato plants with Tecamin Max solution at 2 L ha^{-1} significantly enhanced vegetative traits (plant length, number of plant stems, leaf content of total chlorophyll and the area of the single leaf) relative to the control. Kahlel and Sultan (2019) indicated that drenching Tecamin Max compounds into the soil at a level (3 mL L^{-1}) influentially ameliorated the dry weight of the plant, total chlorophyll content, tuber average weight, tuber size, yield of tubers, whole tubers yield, and NPK content in leaves. Al Khafaji and Oliwi (2020) found that spraying Tecamin Max to potato plants at a rate of 300 ppm excelled all of the investigated characters, such as plant height, number of aerial stems, total yield ton ha^{-1}, dry and wet weight, leaf area and chlorophyll content. Allela *et al.* (2022) sprayed potato plants of cv. Arizona with organic acid (Tecamin Max) and recorded the maximum number of total and marketable tubers for each plant, tuber hardness and the percentage of total soluble solids in tubers at a concentration of 6 mL L^{-1}.

Hence, this research aimed to study the effect of foliar addition of nano NPK fertilizer and Tecamin Max on growth, yield and leaf nutrient content of two potato cultivars under climatic conditions of Duhok province, Kurdistan region, Iraq.

Materials and methods

The study was undertaken in one of the farmers' fields at Dinaran village of Bardarash district, Duhok governorate, Kurdistan region, Iraq during the spring growing season of 2024. The study encompassed the foliar application of nano NPK fertilizer at three levels (0, 2 and 4 g L^{-1}) and Tecamin Max at three concentrations (0, 3 and 6 mL L^{-1}) and their interactions on growth, yield and leaf mineral content of two potato cultivars namely Harry and Lucinda.

Soil samples were taken from the experimental field at random at a depth of (0-30 cm), choosing several sites of the experiment field for analysis of some physical and chemical properties of the field soil before potato tuber seed planting (Table 1).

The experimental field was ploughed twice in perpendicular directions and subsequently divided into three replicates. Each replicate was further divided into (18) experimental units. Each experimental unit consisted of two ridges, each 3.6 m in length and 0.75 m in width, giving a total experimental unit area of 5.4 m². Tubers were planted at a spacing of 30 cm between plants and at a depth of 15 cm. Twelve tubers were planted on each ridge resulting in 24 tubers per experimental unit (12 tubers × 2 ridges). Two potato cultivars were used in the study. The first cultivar "Harry" was imported from France, and produced by Agrico before being supplied by Al Nahar Alawrad Company. The second cultivar, "Lucinda" was imported from the Netherlands, produced by HZPC and supplied by KH Company. Grade E seed tubers of both cultivars were used throughout the study.

Table 1. Some physical and chemical properties of the studied soil in the field

Characteristics	Measuring units	Content
Volumetric distribution of soil separates		
Sand	Percentage (%)	7.9
Silt	Percentage (%)	36
Clay	Percentage (%)	56.1
Soil texture	-	Silty clay
Available nutrient content		
Total-N	mg/kg	21.8
Available phosphorus	mg/kg	3.86
Available potassium	mg/kg	350
Available calcium	$mmol_c l^{-1}$	10.43
Organic matter (OM)	Percentage (%)	1.37
Soil pH	-	7.38
Electrical Conductivity	$ds.m^{-1}$	0.345

Soil analysis conducted in the soil and water science laboratory, College of Agricultural Engineering Science, Dohuk University

The nano NPK fertilizer used in this study contained 12% N, 12% P_2O_5, and 36% K_2O. The product was supplied by Khazra Company, Iran. According to the manufacturer's specifications, the fertilizer consisted of nanoparticles with an average particle size of under 100 nm. Tecamin Max (Agri-Tecno Company, Spain) is a commercial amino acid biostimulant containing 14.4% total amino acids, 13% free amino acids, 8% organic nitrogen, 50% organic matter, 4.5% sulfur trioxide (SO_3), C/N ratio of 2.5, and pH 6.6. Fresh spraying solutions were prepared immediately before each application by dissolving the required quantity of each product in clean water and mixing thoroughly.

The tubers were received 15 days before planting and placed in a shaded place at room temperature (20-26 °C) for about 15 days to stimulate the tubers to sprout before planting. Tubers were planted on March 1, 2024, and harvested on July 1, 2024, representing a growing period of approximately 120 days. Before planting, all plots received the same basal fertilization according to local recommendations, the chemical fertilizer, 600 kg ha^{-1} of Diammonium Phosphate (DAP, 18:46:00) sourced from Russia, was applied via broadcasting to the land about five days prior to potato planting (Esho *et al.,* 2009). The potato plants were sprayed three times with nano NPK fertilizers and Tecamin Max, the first application 15 days after sprouting, the second after 20 days from the first, and the third after 20 days from the second, with a three-day interval between the spraying time of nano NPK fertilizer and Tecamin Max.

Nano NPK fertilizer and Tecamin Max were applied to the same experimental plots with a three-day interval between applications to avoid possible incompatibility during spraying. Therefore, the combined effect represents the cumulative response of plants receiving both treatments rather than the effect of a single mixed spray solution.

The sprinkler irrigation system of the field was performed before planting. Other agricultural practices were similarly carried out as followed by farmers in the area such as weeding (twice during the growing season) and controlling diseases and insects.

Experimental Treatments: The experiment was arranged as a split-split plot within a randomized complete block design (RCBD) with three replications. Cultivars were assigned to the main plots, Tecamin Max treatments to the subplots, and nano NPK fertilizer treatments to the sub-subplots. Data were subjected to analysis of variance (ANOVA) using SAS software (Version 9.4; SAS Institute Inc., Cary, NC, USA). The ANOVA model included replication, cultivar, Tecamin Max, nano NPK fertilizer, and all interaction effects. Appropriate error terms corresponding to the split-split plot structure were used to test the significance of the main effects and interactions. Treatment means were separated using Duncan's Multiple Range Test at the 5% probability level ($P \leq 0.05$).

The following parameters were measured: chlorophyll content

(SPAD) in leaves, number of aerial stems per plant, nitrogen content in leaves (%), phosphorus content in leaves (%), potassium content in leaves (%), plant yield (kg plant^{-1}) and total yield (t ha^{-1}).

For the chemical leaf analysis, leaf samples were collected at the full vegetative growth stage from the most recently fully expanded leaves of five randomly selected plants in each experimental unit. Samples were washed with distilled water, oven-dried at 70°C until constant weight, ground, and stored for chemical analysis. Nitrogen was determined using the Kjeldahl method, phosphorus by the molybdenum blue colorimetric method after wet digestion, and potassium using a flame photometer following standard analytical procedures.

Results

Chlorophyll content in leaves (SPAD): As shown in Table 2, Harry had significantly higher leaf chlorophyll content (44.36 SPAD units) than Lucinda (40.94 SPAD units). Nano NPK at 2 and 4 g L^{-1} increased the chlorophyll content as compared to control. Tecamin Max also increased chlorophyll content with 3 and 6 mL L^{-1} recording 42.89 and 44.29 SPAD units, respectively.

Table 2. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on the leaves chlorophyll content of potato plants

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1})			Cultivars x Nano NPK	Cultivar effect
		0	3	6		
Harry	0	39.47^{ef}	43.85^{b-e}	43.99^{b-e}	42.44^{bc}	44.36^{a}
	2	43.37^{b-e}	45.07^{bc}	44.60^{b-d}	44.34^{ab}	
	4	42.97^{b-e}	46.18^{ab}	49.77^{a}	46.31^{a}	
Lucinda	0	37.12^{f}	40.39^{d-f}	41.89^{b-e}	39.80^{d}	40.94^{b}
	2	41.92^{b-e}	40.07^{d-f}	41.39^{c-f}	41.13^{cd}	
	4	39.79^{ef}	41.77^{b-e}	44.10^{b-e}	41.89^{cd}	
Cultivars x Tecamin Max	Harry	41.93^{bc}	45.03^{a}	46.12^{a}	Nano NPK Effect	
	Lucinda	39.61^{c}	40.75^{bc}	42.46^{b}		
Nano NPK x Tecamin Max	0	38.29^{c}	42.12^{b}	42.94^{b}	41.12^{b}	
	2	42.64^{b}	42.57^{b}	43.00^{b}	42.74^{a}	
	4	41.38^{b}	43.98^{b}	46.94^{a}	44.10^{a}	
Tecamin Max effect		40.77^{b}	42.89^{a}	44.29^{a}		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (P=0.05).

For the two-factor interactions, Lucinda untreated recorded 39.80 SPAD units while Harry treated with 4 g L^{-1} nano NPK recorded 46.31 SPAD units. The highest chlorophyll content was also observed for Harry when used with 3 or 6 mL L^{-1} Tecamin Max. The addition of 4 g L^{-1} nano NPK and 6 mL L^{-1} Tecamin Max resulted in 46.94 SPAD units. Harry (4 g L^{-1} nano NPK + 6 mL L^{-1} Tecamin Max) exhibited the highest overall chlorophyll content (49.77 SPAD units) while untreated Lucinda had the lowest (37.12 SPAD units).

Aerial stems plant^{-1}: The number of aerial stems per plant was not significantly different between Harry and Lucinda as shown in Table 3. However, nano NPK significantly enhanced the stem number; 2 and 4 g L^{-1} gave 4.08 and 4.24 stems plant^{-1}, respectively, compared to 3.84 stems plant^{-1} in the control. Stem number was increased to 4.22 stems plant^{-1} by Tecamin Max at 3 mL L^{-1} compared with 3.87 stems plant^{-1} in untreated plants.

Among the two-factor interactions, Harry treated with 4 g L^{-1} nano NPK produced 4.31 stems plant^{-1} and Harry combined with

Table 3. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on the number of aerial stems plant^{-1} in potato plants

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1})			Cultivars x Nano NPK	Cultivar effect
		0	3	6		
Harry	0	3.73^{c-e}	4.07^{a-e}	4.13^{a-e}	3.98^{bc}	
	2	3.93^{b-e}	4.23^{a-c}	4.07^{a-e}	4.08^{ab}	4.12^{a}
	4	4.00^{b-e}	4.60^{a}	4.33^{ab}	4.31^{a}	
Lucinda	0	3.60^{e}	3.87^{b-e}	3.63^{de}	3.70^{c}	
	2	4.10^{a-e}	4.13^{a-e}	4.00^{b-e}	4.08^{ab}	3.98^{a}
	4	3.87^{b-e}	4.42^{ab}	4.20^{a-d}	4.16^{ab}	
Cultivars x Tecamin Max	Harry	3.89^{bc}	4.30^{a}	4.18^{ab}		
	Lucinda	3.86^{c}	4.14^{a-c}	3.94^{bc}	Nano NPK Effect	
Nano NPK x Tecamin Max	0	3.67^{c}	3.97^{bc}	3.88^{bc}	3.84^{b}	
	2	4.02^{bc}	4.18^{ab}	4.03^{bc}	4.08^{a}	
	4	3.93^{bc}	4.51^{a}	4.27^{ab}	4.24^{a}	
Tecamin Max effect		3.87^{b}	4.22^{a}	4.06^{ab}		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (α=0.05).

3 mL L^{-1} Tecamin Max reached 4.30 stems plant^{-1}. Combining 4 g L^{-1} nano NPK with 3 mL L^{-1} Tecamin Max resulted in 4.51 stems plant^{-1}. The highest overall value (4.60 stems plant^{-1}) was recorded for Harry with 4 g L^{-1} nano NPK and 3 mL L^{-1} Tecamin Max, while the lowest value (3.60 stems plant^{-1}) was recorded for untreated Lucinda.

Nitrogen content in leaves (%): The data presented in Table 4 showed that the nitrogen content in the leaves was significantly higher in the Harry cultivar (2.25%) than in Lucinda (2.09%). The application of nano NPK also significantly affected the leaf nitrogen content, and the highest value (among the tested levels) was recorded with 4 g L^{-1}. Similarly, foliar application of Tecamin Max significantly improved the nitrogen content and the maximum value (2.34%) was recorded at 6 mL L^{-1}.

Also significant was the interaction between cultivar and nano NPK. Harry treated with 4 g L^{-1} nano NPK had the highest nitrogen content (2.46%) compared to other cultivar × nano NPK combinations. Similarly, the cultivar × Tecamin Max interaction indicated that Harry sprayed with 6 mL L^{-1} Tecamin Max had the highest nitrogen content (2.46%).

The interaction between nano NPK and Tecamin Max further improved the leaf nitrogen content. Plants treated with 4 g L^{-1}

Table 4. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on the percentage of nitrogen in potato leaves

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1})			Cultivars x Nano NPK	Cultivar effect
		0	3	6		
Harry	0	1.72^{de}	2.19^{bc}	2.33^{a-c}	2.08^{bc}	
	2	2.05^{cd}	2.26^{bc}	2.31^{a-c}	2.21^{b}	2.25^{a}
	4	2.09^{b-d}	2.54^{ab}	2.74^{a}	2.46^{a}	
Lucinda	0	1.57^{e}	2.03^{cd}	2.27^{bc}	1.96^{c}	
	2	2.11^{b-d}	2.10^{b-d}	2.05^{cd}	2.09^{bc}	2.09^{b}
	4	1.96^{c-e}	2.37^{a-c}	2.34^{a-c}	2.23^{b}	
Cultivars x Tecamin Max	Harry	1.96^{cd}	2.33^{ab}	2.46^{a}		
	Lucinda	1.88^{d}	2.17^{bc}	2.22^{ab}	Nano NPK Effect	
Nano NPK x Tecamin Max	0	1.64^{d}	2.11^{c}	2.30^{a-c}	2.02^{b}	
	2	2.08^{c}	2.18^{bc}	2.18^{bc}	2.15^{b}	
	4	2.03^{c}	2.46^{ab}	2.54^{a}	2.34^{a}	
Tecamin Max effect		1.92^{b}	2.25^{a}	2.34^{a}		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (α=0.05).

nano NPK + 6 mL L^{-1} Tecamin Max recorded 2.54% nitrogen compared to untreated control, which recorded only 1.64%. The interactions of the three factors gave the highest nitrogen content (2.74%) by Harry with 4 g L^{-1} nano NPK and 6 mL L^{-1} Tecamin Max. The lowest value was observed in untreated Lucinda plants (1.57%).

Phosphorus content in leaves (%): There was no significant difference in leaf phosphorus content between the Harry and Lucinda cultivar (Table 5). However, both nano NPK fertiliser and Tecamin Max had significant effects on phosphorus accumulation. The maximum phosphorus contents were obtained with 4 g L^{-1} nano NPK (0.227%) and 6 mL L^{-1} Tecamin Max (0.224%), respectively, compared to the other application levels.

There was also a significant interaction between cultivar and nano NPK. The highest phosphorus content (0.231%) was recorded in Lucinda treated with 4 g L^{-1} nano NPK compared to the other cultivar × nano NPK combinations. Similarly, the interaction between cultivar and Tecamin Max indicated that Lucinda treated with 6 mL L^{-1} Tecamin Max recorded the highest value (0.230%).

The combined application of nano NPK and Tecamin Max also showed significant improvement. In two-factor combinations, the highest phosphorus content (0.241%) was recorded in the treatment of 4 g L^{-1} nano NPK and 6 mL L^{-1} Tecamin Max. Concerning the three-factor interaction, the highest phosphorus content (0.249%) was recorded with Lucinda treated with 4 g L^{-1} nano NPK and 6 mL L^{-1} Tecamin Max, whereas the lowest value (0.175%) was registered with the untreated Harry plants.

Table 5. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on the percentage of phosphorus in potato leaves

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1})			Cultivars x Nano NPK	Cultivar effect
		0	3	6		
Harry	0	0.175^{c}	0.199^{a-c}	0.196^{a-c}	0.190^{c}	
	2	0.190^{bc}	0.207^{a-c}	0.225^{a-c}	0.207^{a-c}	0.207^{a}
	4	0.211^{a-c}	0.227^{a-c}	0.233^{ab}	0.224^{ab}	
Lucinda	0	0.203^{a-c}	0.190^{bc}	0.212^{a-c}	0.202^{bc}	
	2	0.219^{a-c}	0.229^{a-c}	0.228^{a-c}	0.226^{ab}	0.220^{a}
	4	0.220^{a-c}	0.225^{a-c}	0.249^{a}	0.231^{a}	
Cultivars x Tecamin Max	Harry	0.192^{b}	0.211^{ab}	0.218^{ab}	Nano NPK Effect	
	Lucinda	0.214^{ab}	0.215^{ab}	0.230^{a}		
Nano NPK x Tecamin Max	0	0.189^{c}	0.195^{bc}	0.204^{a-c}	0.196^{b}	
	2	0.205^{a-c}	0.218^{a-c}	0.227^{ab}	0.216^{a}	
	4	0.215^{a-c}	0.226^{a-c}	0.241^{a}	0.227^{a}	
Tecamin Max effect		0.203^{b}	0.213^{ab}	0.224^{a}		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (α=0.05).

Potassium content in leaves (%): There was no significant difference in leaf potassium content between the Harry and Lucinda cultivar (Table 6). However, potassium accumulation was significantly affected by nano NPK application. Spraying potato plants with 4 g L^{-1} nano NPK resulted in an increase in potassium content to 2.20% compared to 1.84% in the control. Likewise, Tecamin Max significantly increased potassium content with 3 and 6 mL L^{-1} to 2.07 and 2.16%, respectively.

A significant interaction between cultivar and nano NPK was also observed. Among the cultivar × nano NPK combinations, the highest potassium content (2.24%) was obtained from Lucinda with 4 g L^{-1} nano NPK. The interaction between cultivar and Tecamin Max was also significant, where Lucinda sprayed with 6 mL L^{-1} Tecamin Max showed the highest value (2.24%), compared to the lowest value (1.80%) in untreated Harry plants.

The combination of nano NPK and Tecamin Max also increased leaf potassium content further. The highest value (2.38%) was registered by plants treated with 4 g L^{-1} nano NPK + 6 mL L^{-1} Tecamin Max while the untreated control gave the lowest value (1.65%).

For the three-factor interaction, leaf potassium content was highest (2.44%) in Lucinda treated with 4 g L^{-1} nano NPK and 6 mL L^{-1} Tecamin Max. In contrast, the untreated Harry plants recorded the lowest value (1.61%).

Table 6. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on the percentage of potassium in potato leaves

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1})			Cultivars x Nano NPK	Cultivar effect
		0	3	6		
Harry	0	1.61^{f}	1.87^{c-f}	1.84^{d-f}	1.77^{d}	1.96^{a}
	2	1.83^{d-f}	1.98^{b-f}	2.05^{a-e}	1.95^{b-d}	
	4	1.97^{b-f}	2.18^{a-d}	2.32^{ab}	2.16^{ab}	
Lucinda	0	1.69^{fe}	1.97^{b-f}	2.06^{a-e}	1.91^{cd}	2.07^{a}
	2	1.82^{d-f}	2.14^{a-d}	2.23^{a-d}	2.06^{a-c}	
	4	1.99^{b-f}	2.28^{a-c}	2.44^{a}	2.24^{a}	
Cultivars x Tecamin Max	Harry	1.80^{c}	2.01^{bc}	2.07^{ab}	Nano NPK Effect	
	Lucinda	1.83^{c}	2.13^{ab}	2.24^{a}		
Nano NPK x Tecamin Max	0	1.65^{e}	1.92^{cd}	1.95^{b-d}	1.84^{c}	
	2	1.82^{de}	2.06^{b-d}	2.14^{a-c}	2.01^{b}	
	4	1.98^{b-d}	2.23^{ab}	2.38^{a}	2.20^{a}	
Tecamin Max effect		1.82^{b}	2.07^{a}	2.16^{a}		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (α=0.05).

Plant yield (kg plant^{-1}): The data presented in Table 7 show that the Harry cultivar had a significantly higher plant yield (1.309 kg plant^{-1}) than Lucinda (1.169 kg plant^{-1}). Nano NPK at 4 g L^{-1} had the highest yield (1.313 kg plant^{-1}) followed by 2 g L^{-1} (1.276 kg plant^{-1}). Application of Tecamin Max (3 mL L^{-1}) significantly increased the yield, where it was 1.372 kg plant^{-1} compared to 1.069 kg plant^{-1} in control.

Table 7. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on plant yield (kg plant^{-1}) of potato plants

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1})			Cultivars x Nano NPK	Cultivar effect
		0	3	6		
Harry	0	0.998^{ef}	1.235^{c-e}	1.288^{b-d}	1.173^{cd}	1.309^{a}
	2	1.179^{c-f}	1.582^{a}	1.310^{b-d}	1.357^{ab}	
	4	1.095^{d-f}	1.596^{a}	1.499^{ab}	1.397^{a}	
Lucinda	0	0.919^{f}	1.174^{c-e}	1.153^{c-e}	1.082^{d}	1.169^{b}
	2	1.126^{c-f}	1.281^{b-d}	1.179^{c-f}	1.195^{cd}	
	4	1.096^{d-f}	1.366^{a-c}	1.229^{c-e}	1.230^{bc}	
Cultivars x Tecamin Max	Harry	1.090^{de}	1.471^{a}	1.366^{ab}	Nano NPK Effect	
	Lucinda	1.047^{e}	1.274^{bc}	1.187^{cd}		
Nano NPK x Tecamin Max	0	0.958^{d}	1.204^{bc}	1.221^{bc}	1.128^{b}	
	2	1.152^{c}	1.431^{a}	1.245^{bc}	1.276^{a}	
	4	1.096^{cd}	1.481^{a}	1.364^{ab}	1.313^{a}	
Tecamin Max effect		1.069^{c}	1.372^{a}	1.276^{b}		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (α=0.05).

The maximum yield was obtained in two-factor interactions with

Harry with nano NPK (4 g L^{-1}) (1.397 kg $plant^{-1}$) and Harry with Tecamin Max (3 mL L^{-1}) (1.471 kg $plant^{-1}$). The combination of 4 g L^{-1} nano NPK and 3 mL L^{-1} Tecamin Max produced 1.481 kg $plant^{-1}$. The highest total plant yield (1.596 kg $plant^{-1}$) was obtained from Harry treated with 4 g L^{-1} nano NPK and 3 mL L^{-1} Tecamin Max whereas untreated Lucinda produced the lowest yield (0.919 kg $plant^{-1}$).

Total yield (t ha^{-1}): Table 8 shows that the total yield of Harry was significantly higher than Lucinda (58.18 t ha−1 vs. 51.96 t ha−1). Nano NPK at 2 and 4 g L^{-1} increased total yield to 56.71 and 58.38 t ha^{-1}, respectively compared with control (50.12 t ha^{-1}). Tecamin Max at 3 and 6 mL L^{-1} gave 60.98 and 56.73 t ha^{-1}, respectively, compared with 47.50 t ha^{-1} in untreated plants.

For the two-factor interaction, Harry treated with 4 g L^{-1} nano NPK produced 62.07 t ha^{-1}, Harry treated with 3 mL L^{-1} Tecamin Max produced 65.37 t ha^{-1}, while the combination of 4 g L^{-1} nano NPK and 3 mL L^{-1} Tecamin Max had 65.82 t ha^{-1}. The highest total yield was obtained by the three-factor interaction with 4 g L^{-1} nano NPK and 3 mL L^{-1} Tecamin Max, reaching 70.93 t ha^{-1}. Conversely, untreated Lucinda produced the lowest yield (40.84 t ha^{-1}).

Table 8. Effect of cultivars, nano NPK fertilizers, Tecamin Max and their interaction on total yield of tuber (t ha^{-1}) of potato

Cultivars	Nano NPK (g L^{-1})	Tecamin Max (mL L^{-1}) 0	3	6	Cultivars x Nano NPK	Cultivar effect
Harry	0	44.35 ef	54.88 c-e	57.24 b-d	52.15 cd	58.18 a
	2	52.39 c-f	70.31 a	58.22 b-d	60.30 ab	
	4	48.66 d-f	70.93 a	66.62 ab	62.07 a	
Lucinda	0	40.84 f	52.18 c-f	51.24 c-f	48.09 d	51.96 b
	2	50.04 c-f	56.93 b-d	52.39 c-f	53.12 cd	
	4	48.71 d-f	60.71 a-c	54.62 c-e	54.68 bc	
Cultivars x Tecamin Max	Harry	48.44 de	65.37 a	60.71 ab	Nano NPK Effect	
	Lucinda	46.53 e	56.62 bc	52.75 cd		
Nano NPK x Tecamin Max	0	42.58 d	53.51 bc	54.26 bc	50.12 b	
	2	51.22 c	63.60 a	55.33 bc	56.71 a	
	4	48.71 cd	65.82 a	60.62 ab	58.38 a	
Tecamin Max effect		47.50 c	60.98 a	56.73 b		

The column, row and their interactions with the same letters are not significantly different from each other according to Duncan's multiple range test at level (α=0.05).

Discussion

Results of Tables (2, 4, 7, and 8) displayed significant differences between the cultivars in vegetative growth, quantitative yield and mineral leaf content traits of potato. Harry cultivar was superior to the Lucinda cultivar in most studied traits in this study. This may be attributed to genetic differences between the cultivars, resulting from the variation in genetic features related to vegetative growth characters (Merga and Dechassa, 2019; Al-Quraishi and Al-Bayati, 2019). These results are consistent with those of Al-Bayati *et al.* (2020) who revealed that the Sylvana cultivar was superior in the percentage of total chlorophyll over the Arizona and Volar cultivars of potato.

Al-Abdali *et al.* (2021) also showed that the Montreal cultivar produced significantly greater vegetative growth as compared with Arizona cultivar. Kahlel *et al.* (2021) studied the response of four potato cultivars (Arizona, Florice, Laperla, Montreal) to foliar application of 2 g L^{-1} of Nano fertilizers and illustrated that Florice cultivar recorded the highest value of plant height, nitrogen percentage and phosphorus percentage in leaves but the highest leaf area and dry matter % was found in Montreal cultivar whereas the significant chlorophyll and potassium content in leaves was recorded for Laperla cultivar.

The results demonstrated that application of 4 g L^{-1} nano NPK fertilizer significantly improved all studied parameters. This response might be attributed to the effectiveness of chelated nano-fertilizer on various physiological activities like improving the chlorophyll formation, which is required for the elevation of the photosynthetic efficiency and the manufacture of the amino acid (Tryptophan), which is essential for cell enlargement. Furthermore, nano fertilizers are characterized by a small particle size (<100 nm), thus having the ability to hold several ions due to their large surface area, which triggers them slowly as per crop requirement (Al-Juthery *et al.* 2018; Ahmed *et al.* 2023).

Another reason might also be associated with the enhanced nutrient use efficiency of nano fertilizer. Their nanoscale dimensions increase nutrient solubility and mobility, allowing nutrients to be absorbed more efficiently and supplied according to plant demand (Al-Taey and Burhan, 2022) and hence approaching the plant a status of premium nourishment equilibrium that positively reflected on the yield attributes (Al-Zaidi and Al-Mharib, 2025; Al-Taey and Burhan, 2022; Al-Bayati *et al.* 2019).

The results also demonstrated that Tecamin Max at concentrations of 3 mL L^{-1} and 6 mL L^{-1} significantly improved vegetative growth, yield and leaf mineral content compared with the control treatments. This may be attributed to the ability of Tecamin Max to enhance protein and phytohormone biosynthesis, enzyme activation, macro- and microelement uptake, signalling pathways and energy production (Souri and Hatamian, 2019). Such beneficial effects may also be attributed to the ability of Tecamin Max to directly or indirectly affect the physiological operations of the plant and influence enzymes involved in photosynthetic processes. Al-Zebari and Sarhan (2019) reported that applying 4 g L^{-1} humic acid to summer squash improved fruit number, fruit length, fruit diameter, average fruit weight and total yield. Shareef *et al.* (2022) concluded that spraying summer squash with Tecamin Max increased chlorophyll amount, number of fruit $plant^{-1}$, plant yield kg $plant^{-1}$ and total yield t ha^{-1}.

It can be concluded from this study that the cultivars differed in foliage traits, leaf nutrient composition and yield with Harry showing superior performance compared with Lucinda. Moreover, treating potato plants with nano NPK fertilizer at a rate of 4 g L^{-1} significantly improved all parameters relative to other treatments. Furthermore, the foliar application of Tecamin Max at a rate of 3 mL L^{-1} gave the maximum results in the number of aerial stems, plant and total yield traits, whereas foliar application at 6 mL L^{-1} was most effective in enhancing chlorophyll SPAD value and leaf mineral composition. Based on the results obtained during one growing season at a single experimental site, it is recommended to conduct further multi-location and multi-season experiments to validate and refine the findings before making broad agronomic recommendations.

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