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Bulb yield, macromineral and phytochemical contents of garlic varieties grown with phosphorus fertilization in calcareous soil

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Abstract

The objectives of this study were to investigate the effects of phosphorus (P) fertilizer application on bulb yield, macromineral and phytochemical contents of two garlic (*Allium sativum*) varieties 'Balady' and 'Northern White' grown in calcareous soil under field conditions in north Jordan. Three P fertilizer rates were applied [0 (control; P1), 43.6 (P2) and 87.2 (P3) Kg P ha^{-1} added as super phosphate]. When compared to P1 (control), application of P at P3 rate increased bulb yield by 49% and 43%, mean bulb weight by 34% and 27% and cloves number per bulb by 35% and 29% in 'Balady' and 'Northern White' varieties, respectively. The total phenols and flavonoids contents and antioxidant activity were significantly higher in cloves of both garlic varieties at P2 rate than at P1 and P3 rates. However, clove flavonoids and allicin contents and antioxidant activity were significantly higher in 'Balady' than 'Northern White' variety at P2 rate only. For mineral contents, P was found to be highest in cloves of both garlic varieties at the P3 rate, while N and Ca contents were highest at the P2 rate. Cloves of 'Balady' variety had higher P content than cloves of 'Northern White' variety at medium (P2) and high (P3) P rates, while Ca contents were found in 'Northern White' than the 'Balady' variety at medium P (P2) rates. Results of this study suggest that the bulb yield and nutritional quality of garlic differed with different rates of applied P fertilization and selection of variety/cultivar under calcareous soil conditions.

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Introduction

Garlic (*Allium sativum* L.) is an important vegetable crop that is cultivated and consumed throughout the world for its clove medicinal and nutritional properties. In 2020, the world total production of garlic was 48.8 million tons and the total harvested area was about 2.5 million ha[1]. Garlic cloves are a good source of minerals (e.g., Ca, P, and K) and a rich source in health-promoting bioactive compounds as natural antioxidants that have positive effects on health[2,3]. Garlic cloves also contain a biologically active sulfur-containing compound called allicin responsible for its smell and taste[4−7]. Garlic quality components hold promise as an excellent source for the development of functional foods[4]. Many studies indicate that garlic has pharmaceutical effects and is used to cure several diseases like blood pressure, asthma, cholesterol, chronic fever, anthelmintic, wound healing, arthritis, diabetes, and kidney stones[4,8,9].

Garlic production under particular environmental conditions is influenced by different factors like climate conditions, soil properties, cultivation practices (e.g., fertilizer application) and cultivar/variety[10,11]. Garlic plants need an adequate supply of readily available nutrients for optimum growth and yield, and can be reasonably responsive to P fertilization, particularly in low available P soils like calcareous soils[12,13]. Soil P availability to plants is significantly reduced by high soil pH as the case in alkaline and calcareous soils which prevail in arid and semiarid regions (e.g., Jordan) which might be developed due to poorly soluble calcium phosphate compounds that reduce the rate of phosphate uptake by roots and hence become one of the biggest limitations to garlic production[14−16]. The application of P fertilizer in alkaline and calcareous soils following the recommended rates may not result in optimal crop growth, and relatively high P application rates might be required in calcareous soils to guarantee adequate bulb yield[17,18] as well as high nutritive values[19]. Application of P to garlic commonly ranges from 21.8 to 65.4 kg P ha^{-1} depending on soil P level, crop variety, and soil characteristics[12,13,20].

There is a growing interest in enhancing the nutritive value of garlic bulbs including the levels of phenolic compounds and mineral contents. Many researchers suggested that many plant species of the genus *Allium* are characterized by high levels of polyphenoles and antioxidants which are affected by genotype characteristics (variety/cultivar) modified by environmental conditions and cultivation practices such as fertilization strategies[3,21−23]. In this context, P supply affects growth and secondary metabolites in plants such as flavonoids, phenolics and allicin contents[19,24,25]. Pontigo et al.[26] found a strong relationship between phenol assimilation and P efficiency (the effectiveness of uptake and internal utilization of P). However, P deficiency is common in the calcareous soils, which encompass more than 50% of the total cultivated area of the Mediterranean region[27,28].

Phosphorus fertilizer application has been reported to influence plant growth and quality which has been evaluated in different crops including garlic under different soils and environmental conditions but information concerning calcareous soils is not well investigated. Garlic bulb yield and nutritional value (phenols, antioxidants and minerals) might be greatly affected by imbalanced and low availability of soil nutrients such as P especially in alkaline soils prevailing in arid and semiarid regions (e.g., Jordan) due to low native content and high P immobilization within the soil[14,17,27].

As Jordan imports a significant proportion of its garlic supply from China[29], some farmers started to cultivate some Chinese varieties along with local varieties especially in northern Jordan where calcareous soils are predominant. The Jordanian garlic cultivars was found to belong to the type or subspecies (*Allium sativum* var. *sativum*), while the Chinese garlic cultivars belong to the type or subspecies (*Allium sativum* var. *ophioscordon*). In this study, one Jordanian local variety: *Allium sativum* var. *sativum* 'Balady' was compared with a Chinese white variety: *Allium sativum* var. *ophioscordon* 'Northern White'.

The objectives of this research were to study the effects of P fertilizer application rates [0 (control, P1), 43.6 (P2) and 87.2 (P3) Kg P ha^{-1}) on bulb yield, mineral and phytochemical contents of two garlic varieties ('Baladi' and 'Northern White') grown in calcareous soil conditions in north Jordan.

Materials and methods

Experimental site description

A field experiment was conducted during the 2022/2023 growing season at the experimental field of the Faculty of Agriculture, Jordan University of Science and Technology (JUST), Irbid, Jordan (32°34' N latitude; 36°01' E longitude; and 520 m altitude). The soil type at this site is classified as silty clay (fine, mixed, thermic, Typic Xerochrept) which is considered as alkaline and calcareous soil. The JUST location typically experiences moderate to severe drought stress during the growing season. The long-term average of annual rainfall at the site is about 225 mm. During the growing season of garlic, the minimum and maximum temperatures were 8.5 and 32 °C, respectively. Composite soil samples were taken randomly from the experimental area before starting the experiment at a depth of 25 cm and analyzed for major soil properties (Table 1).

Land preparation

At the beginning of the growing season, the experimental plots were plowed, disked and raised beds were prepared for planting, with six 10-cm-deep planting furrows in each experimental plot. Plot dimensions were 4.0 m × 2.4 m. This was followed by the installation of a drip irrigation system with a line in each planting furrow.

Treatments, planting, and agronomic practices

The treatments consisted of different P fertilizer rates and two garlic varieties. The phosphorus was applied in the form of superphosphate with three rates which include [0 (control; P1), 43.6 (P2) and 87.2 (P3) Kg P ha^{-1}]. Phosphorus fertilizer was applied in bands in the planting furrows and incorporated in the soil below ~10 cm to one side where the garlic cloves were to be planted. The experimental plots were pre-irrigated one day before planting.

Table 1. Physical and chemical properties of the experimental soil before planting (0–25 cm).

Texture	pH	Salinity EC (dS·m^{-1})	OM	$CaCO_3$	Total N	Available (mg·kg^{-1})				
						P	K	Ca	Mg	Na
Silty clay	8.2	0.8	1.1%	16.7%	0.8%	6.0	156	171	51	0.61

EC, electrical conductivity; OM, organic matter.

Mature bulbs of two garlic varieties: Local Jordanian 'Balady' (skin color of bulb is purple-striped) and Chinese variety 'Northern White' (the skin color of the bulb is white) were obtained from local market and used in this study. Garlic bulbs were separated into cloves, large and medium-sized cloves were selected and their scale leaves were removed to enhance clove sprouting. Planting of garlic cloves was done manually in November 2022 at a depth of 8 cm on the prepared plots at a spacing of 40 cm between rows and 20 cm between plants. Planting plots (4.0 m × 2.4 m) were separated by 0.6 m buffer area. The experimental field was supplementary irrigated by a drip irrigation system as needed to keep soil moisture at adequate levels for plants growth. The total rainfall during the growing season was 170 mm. Nitrogen fertilizer in form of Urea (46% N) was applied uniformly by hand across all treatments (40 kg N ha^{-1} in the planting furrows at planting, 30 and 30 kg N ha^{-1} top-dressed at 60 and 120 d after planting). When needed, weeds were controlled by hand.

Harvesting and measurements

At the end of June 2023, when the lower two-thirds of leaves had dried up and turned brown, the garlic plants in four central rows of each plot were harvested without the border plants. Before harvest, plant heights were measured. After harvest, plants were cured (dried) in a greenhouse for 2 weeks. After curing, the stem was cut above 3–4 cm and the roots trimmed up to 3 cm. Weights of all cured bulbs per plot were recorded in grams and converted to tons per hectare (bulb yield·ha^{-1}). Data on average bulb weight and number of cloves/bulbs were taken using five randomly sampled bulbs from each plot/replicate.

Macro mineral analysis

Five bulbs were selected randomly from each plot/replicate, their cloves were separated, scale leaves removed and oven-dried for 4 d at 65 °C. Subsequently, weights of dried cloves were determined and the material was stored at room temperature for mineral analysis.

A representative sub-sample (0.5 g) from oven-dried garlic cloves from both varieties of every treatment were ground to pass a 0.5 mm sieve in a cyclone laboratory mill and saved for mineral analysis. These ground samples were weighed into crucibles, ashed for 5 h in a muffle furnace (550 °C), and suspended with 5 mL 2 N HCl for macromineral determination. The samples were filtered into glass vials using filter paper (Whatman #1). Then, 1 mL of filtered solution was transferred into a 25-mL volumetric flask and 1 M HCl was used to fill the flask to a determined volume. Flame Atomic Absorption Spectrometer (Varian AA 240 FS) was used to determine P, K, Ca, and Mg. Kjeldahl's method was used for analyzing N content[30]. The testing agents and standards used for mineral analysis were of analytical grade.

Determination of total phenols and flavonoid content and antioxidant activity

Five garlic bulbs were selected randomly from each plot/replicate, and their cloves were separated and cut into pieces that were air-dried at room temperature for about 8–10 d.

Air-dried clove samples were randomly selected and ground and used for the determination of total phenols and total flavonoid contents and antioxidant activities. Dry clove samples were extracted in chemical solvents (methanol/water) and prepared for chemical analysis according to the procedures described by Llorach et al.[31]. The total phenolic contents of the clove solvent extracts were determined by the Folin - Ciocalteu spectrophotometric method as described by Singleton & Rossi[32], and the readings were compared with a calibration curve using gallic acid as a standard. Total content of phenols were expressed as of Gallic acid equivalent (GAE) (mg GAE/100 g DW). The content of flavonoids were quantified based on the method described by Jia et al.[33]. Results were expressed as mg Catechin equivalent (CE)/100 g DW).

The antioxidant activity of clove extract was evaluated according to the method described by Brand-Williams et al.[34] using the 2, 2- diphenyl-1-picrylhydrazyl (DPPH) to determine their ability to scavenge free radicals. The radical scavenging activity was measured as a decrease in the absorbance at 517 nm of DPPH solution and calculated in percentage using the following equation:

$$\text{Radical scavenging activity (\%)} = \left(1 - \frac{\text{Absorbance of sample}}{\text{Absorbance of control}}\right) \times 100$$

Determination of allicin content

After harvesting and curing garlic bulbs, three bulbs were selected randomly from each plot/replicate, their cloves were separated and cut into pieces and subsamples were weighed and used for evaluation of allicin content according to the method described by Prati et al.[35]. Selected garlic samples were weighed (2.0 g) into 100 mL beakers, pressed and soaked in 25 mL of cold water (4 °C), and shaken vigorously. Another 25 mL of cold water was added to the samples and shaken vigorously to dilute and mix the solutions. Each sample was filtered through a 0.45 µm filter membrane into HPLC vials and capped. The analyses were conducted using a high-performance liquid chromatograph (Agilent Technologies, Palo Alto, CA, USA). Using a calibration curve, allicin content in garlic samples were quantified against an isolated allicin external standard.

Experimental design and statistical data analysis

All data are presented as the mean ± standard error of three replicates and were analyzed using SAS software (Version 9.4 for Windows; SAS Institute, Cary, NC, USA), following two-way analysis of variance (ANOVA). Significant differences ($p \leq 0.05$) among treatment, means were determined from a least significant difference (LSD) test.

Results

Bulb yield

The results of this study revealed that the main effect of P fertilizer significantly ($p \leq 0.05$) affected plant height (Fig. 1) and garlic yield (bulb yield, mean bulb weight, and cloves number per bulb) which all attained maximum values at the P3 fertilizer rate in both tested varieties (Table 2). However, the enhancement in bulb yield due to the application of P fertilizer was more pronounced in the 'Balady' than in the 'Northern White' variety regardless of the applied P rate. No significant differences between the tested varieties for bulb yield, mean bulb weight, and cloves number per bulb at no added P fertilizer (P1) treatment (Table 2).

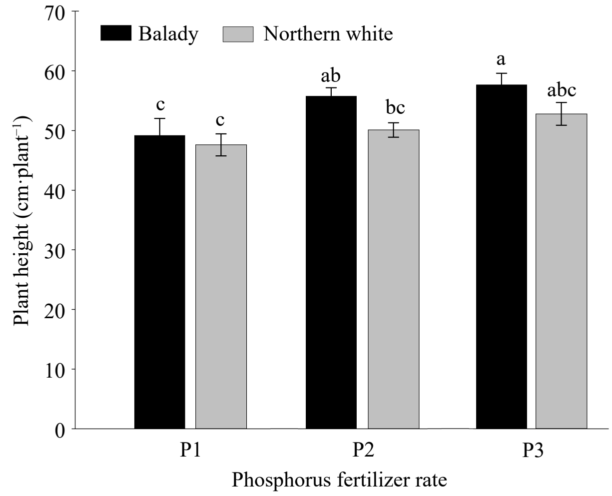

Fig. 1 Plant height of two garlic varieties ('Balady' and 'Northern White') grown under different P fertilizer rates [0 (control) (P1), 43.6 (P2) and 87.2 (P3) kg P ha^{-1})] in calcareous soil. Data represents ± SE. Different letters indicate significant differences at $p \leq 0.05$.

Table 2. Mean (± SE) of bulb yield, mean bulb weight and number of cloves/bulb of two garlic varieties ('Balady' and 'Northern White') grown under different P fertilizer rates [0 (control) (P1), 43.6 (P2) and 87.2 (P3) kg P ha^{-1})] in calcareous soil.

Phosphorus rate	Variety	Bulb yield (ton·ha^{-1})	Mean bulb weight (g)	Cloves no. bulb^{-1}
P1	'Balady'	8.01 ± 0.50 d	25.4 ± 1.4 c	6.33 ± 0.9 c
	'Northern White'	7.40 ± 0.13 d	23.9 ± 1.6 c	6.20 ± 0.5 c
P2	'Balady'	10.5 ± 0.26 b	31.0 ± 3.0 ab	7.93 ± 0.7 ab
	'Northern White'	9.31 ± 0.62 c	27.7 ± 2.0 bc	7.57 ± 0.6 b
P3	'Balady'	11.9 ± 0.31 a	34.1 ± 3.0 a	8.53 ± 0.3 a
	'Northern White'	10.6 ± 0.59 b	30.4 ± 2.2 ab	8.00 ± 0.5 ab
Significance				
Phosphorus (P)		***	**	***
Cultivar (C)		**	*	NS
P × C		NS	NS	NS

Different letters in the same column indicate significant difference at $p \leq 0.05$. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.0001$. NS, not significant. SE, standard error.

The overall effects of P fertilizer application on the garlic yield (bulb yield, mean bulb weight, and cloves number per bulb) (percentage-wise) in plants of both varieties ('Balady' and 'Northern White') grown in calcareous soil are summarized in Table 3. Compared to control treatment (P1), bulb yield was increased by about 31% and 49% in 'Balady' and 26% and 43% in 'Northern White' variety at P2 and P3 rates, respectively. Similarly, mean bulb weights and cloves number/bulb were increased by about 34% and 35% in 'Balady' variety and about 27% and 29% in 'Northern White' variety at P2 in comparison to unfertilized treatment, respectively (Table 3). The enhancement in bulb yield and mean bulb weight due to P fertilizer application was more pronounced in 'Balady' than 'Northern White' variety especially at the high P rate (P3) in comparison to unfertilized treatment (Table 3).

Table 3. Percentage (± SE) change in plant growth (bulb yield, bulb weight and cloves number per bulb) of two garlic varieties ('Balady' and 'Northern White') grown at P fertilizer (PF) or no added P fertilizer (nonPF) in calcareous soil.

P fertilizer rate	Variety	Plant growth¶		
		Bulb yield (%)	Mean bulb weight (%)	Cloves no. per bulb (%)
P2	'Balady'	31 ± 3.0	22 ± 3.3	25 ± 1.7
	'Northern White'	26 ± 2.1	16 ± 2.1	22 ± 2.6
P3	'Balady'	49 ± 7.4	34 ± 3.9	35 ± 4.4
	'Northern White'	43 ± 4.9	27 ± 3.5	29 ± 2.7

¶ Plant growth (PG) change (%) = $((PG_{PF} - PG_{nonPF}) \times 100)/PG_{nonPF}$).

Macronutrient content

In terms of mineral contents in garlic cloves, the highest P contents were found in cloves of both varieties at the high P rate (P3) (Table 4). Contents of P, N, K, and Mg in garlic cloves of both varieties were generally higher at both medium an d high P rates (P2 and P3) than the non-fertilized treatment (P1) (Table 4). Calcium contents in garlic cloves of both varieties were found significantly higher at the medium P rate (P2) than at high P rate (P3) or no added P (P1) (Table 4). Cloves of 'Balady' variety had generally higher contents of N, P, and K than 'Northern White' variety regardless of P rate, while 'Northern White' variety had higher Ca than 'Balady' variety at the P2 rate (Table 4). No differences between varieties for clove contents of Mg regardless of P rate. Results showed also no significant differences between varieties in no P fertilized plots (P1) for all studied minerals (Table 4).

The overall effects of P fertilizer application on the mineral contents (N, P, K, Ca, and Mg) (percentage-wise) in plants of both varieties ('Balady' and 'Northern White') grown in calcareous soil are summarized in Table 5. Application of P fertilizer at the rate P2 had increased garlic clove nutrient contents of N by 9.1% and 8.1%, P by 22.1% and 15%, K by 3.2% and 4.2%, Ca by 68% and 68.4% and Mg by 28.8% and 27.7% in 'Balady' and 'Northern White' varieties, respectively (Table 5). The enhancement in clove P, K, and Mg contents were more pronounced in both varieties with application of P3 than P2 rate. Enhancement in N and P contents due to the application of P fertilizer were more pronounced in 'Balady' than in 'Northern White' variety, while enhancement in K content in 'Northern White' was higher than 'Balady' variety regardless of applied P rate (Table 5).

Phenols, flavonoids, and allicin contents and antioxidant activity

The response of total phenols and flavonoids contents and antioxidant activity in cloves of both garlic varieties to different rates of soil P fertilization is presented in Table 6. The values of the total phenols and flavonoids contents and antioxidant activity were higher at P2 rate than at P1 (control) or P3 rate in both tested varieties. For varieties, the total phenols and flavonoids contents and antioxidant activity were generally higher in 'Balady' than 'Northern White' variety regardless of the applied P rate (Table 6).

The response of allicin contents of cloves of both tested varieties to P fertilization application is presented in Fig. 2. Results showed that allicin contents were highest at both P2 and P3 rates regardless of tested variety. However, allicin contents were higher in 'Balady' than 'Northern White' variety regardless of applied P rate (Fig. 2).

The overall effects of P fertilizer application on the total phenols and flavonoids contents and antioxidant activity (percentage-wise) in plants of both varieties ('Balady' and 'Northern White') grown in calcareous soil are summarized in Table 7.

Table 4. Mean (± SE) of macronutrient concentrations in cloves of two garlic varieties ('Balady' and 'Northern White') grown under different P fertilizer rates [0 (control) (P1), 43.6 (P2) and 87.2 (P3) kg P ha^{-1})] in calcareous soil.

Phosphorus rate	Variety	N	P	K	Ca	Mg
		mg·g^{-1} DM				
P1	'Balady'	2.43 ± 0.10 bc	2.26 ± 0.06 e	15.5 ± 0.06 bc	2.47 ± 0.13 d	0.59 ± 0.04 c
	'Northern White'	2.36 ± 0.08 c	2.20 ± 0.02 e	14.6 ± 0.06 c	2.63 ± 0.08 d	0.65 ± 0.09 bc
P2	'Balady'	2.65 ± 0.11 a	2.76 ± 0.03 c	16.0 ± 0.07 ab	4.15 ± 0.08 b	0.76 ± 0.08 ab
	'Northern White'	2.55 ± 0.05 ab	2.53 ± 0.07 d	15.3 ± 0.08 bc	4.43 ± 0.13 a	0.83 ± 0.09 a
P3	'Balady'	2.57 ± 0.11ab	3.40 ± 0.14 a	16.7 ± 0.04 a	3.09 ± 0.07 c	0.79 ± 0.12 ab
	'Northern White'	2.44 ± 0.08 bc	3.13 ± 0.13 b	16.1 ± 0.04 ab	3.26 ± 0.13 c	0.87 ± 0.10 a
Significance						
Phosphorus (P)		*	***	**	**	**
Cultivar (C)		*	**	*	**	NS
P × C		NS	NS	NS	NS	NS

Different letters in the same column indicate significant difference at $p \leq 0.05$. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.0001$. NS, not significant. SE, standard error.

Table 5. Percentage (± SE) change in fodder mineral (N, P, K, Ca, and Mg) contents of two garlic cultivars ('Balady' and 'Northern White') grown at P fertilizer (PF) or no added P fertilizer (nonPF) in calcareous soil.

P fertilizer rate	Variety	Nutrient content§				
		N (%)	P (%)	K (%)	Ca (%)	Mg (%)
P2	'Balady'	9.1 ± 1.4	22.1 ± 3.0	3.2 ± 0.6	68.0 ± 6.6	28.8 ± 3.3
	'Northern White'	8.1 ± 1.2	15.0 ± 1.8	4.8 ± 0.7	68.4 ± 5.7	27.7 ± 3.1
P3	'Balady'	5.8 ± 0.8	50.4 ± 5.4	7.7 ± 1.2	25.1 ± 4.4	33.9 ± 5.0
	'Northern White'	3.4 ± 0.6	42.3 ± 5.5	10.3 ± 1.4	23.9 ± 3.8	33.8 ± 4.6

§Nutrient content (NC) change (%) = $((NC_{PF} - NC_{nonPF}) \times 100)/NC_{nonPF}$).

Table 6. Mean (± SE) of total phenols and flavonoids contents and antioxidant activity (dry matter basis) in cloves of two garlic varieties ('Balady' and 'Northern White') grown under different P fertilizer rates [0 (control) (P1), 43.6 (P2) and 87.2 (P3) kg P ha^{-1})] in calcareous soil.

Phosphorus rate	Variety	Total phenols (mg GAE 100 g^{-1})	Total flavonoids (mg CE 100 g^{-1})	Antioxidant activity (%)
P1	'Balady'	582 ± 27 b	56.9 ± 5.2 c	27.6 ± 1.3 bcd
	'Northern White'	535 ± 38 c	53.2 ± 4.9 c	24.2 ± 1.6 d
P2	'Balady'	684 ± 25 a	71.7 ± 6.2 a	34.8 ± 1.8 a
	'Northern White'	663 ± 18 a	63.5 ± 4.4 b	29.3 ± 2.8 bc
P3	'Balady'	591 ± 23 b	58.3 ± 4.1 bc	30.7 ± 2.7 b
	'Northern White'	574 ± 19 bc	54.6 ± 3.9 c	26.5 ± 3.2 cd

Different letters in the same column indicate significant difference at $p \leq 0.05$. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.0001$. NS, not significant. SE, standard error.

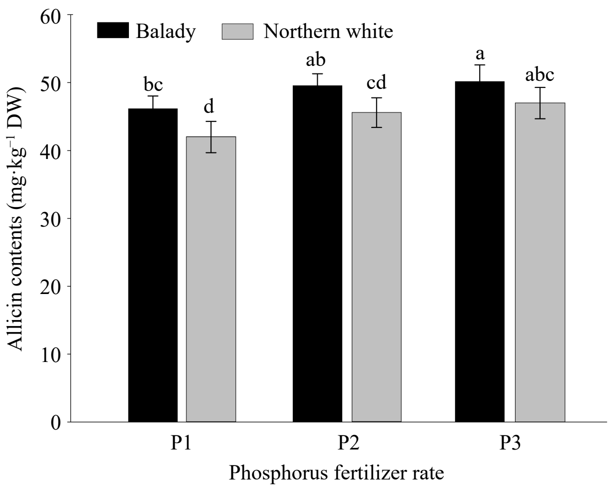

Fig. 2 Allicin contents in cloves of two garlic varieties ('Balady' and 'Northern White') grown under different P fertilizer rates [0 (control) (P1), 43.6 (P2) and 87.2 (P3) kg P ha^{-1})] in calcareous soil. Data represents ± SE. Different letters indicate significant differences at $p \leq 0.05$.

Application of P fertilizer at the rate P2 had increased garlic clove contents of total phenols by 17.5% and 23.9%, flavonoids by 23% and 16.3%, and antioxidant activity by 26% and 21% in 'Balady' and 'Northern White' varieties, respectively (Table 7).

The enhancement due to P fertilizer application in flavonoid contents and antioxidant activity was more pronounced in 'Balady' than 'Northern White' variety, while it was higher for total flavonoids content in 'Northern White' than in 'Balady' variety at medium P rate (P2) (Table 7).

Discussion

The results of this study indicated that the application of P fertilizer at high rates (P2 and P3) potentially improved plant growth (plant height) and garlic productivity (bulb yield, mean bulb weight and cloves number per bulb) in both tested garlic varieties over the unfertilized (P1) plots. These results indicate that increased availability of P in soils had a significant effect on the vegetative growth of garlic and the collective effect of nutrients that stimulate plant growth and thus increases leaf

Table 7. Percentage (± SE) change in total phenols and flavonoids contents and antioxidant activity of two garlic cultivars ('Balady' and 'Northern White') grown at P fertilizer (PF) or no added P fertilizer (nonPF) in calcareous soil.

Phosphorus rate	Variety	Total phenols content (%)¶	Total flavonoid content (%)§	Antioxidant activity (%)*
P2	'Balady'	17.5 ± 2.0	23.0 ± 2.1	26.0 ± 3.4
	'Northern White'	23.9 ± 2.2	16.3 ± 1.6	21.0 ± 3.0
P3	'Balady'	1.5 ± 0.2	2.5 ± 0.3	11.2 ± 1.3
	'Northern White'	7.2 ± 0.5	2.6 ± 0.2	9.5 ± 1.2

¶Phenol content (PC) change (%) = $((PC_{PF} - PC_{nonPF}) \times 100)/PC_{nonPF}$). §Flavonoid content (FC) change (%) = $((FC_{PF} - FC_{nonPF}) \times 100)/FC_{nonPF}$). *Antioxidant activity (AA) change (%) = $((AA_{PF} - AA_{nonPF}) \times 100)/AA_{nonPF}$).

growths of garlic. This is associated with high chlorophyll content and hence results in high photoassimilate production at high P fertilizer rates[19,36]. These results agree with the work of Jitarwal et al.[19] and Büll et al.[10] who reported that increasing the rate of P fertilizer application rate increase garlic bulb yield and number of cloves per bulb significantly.

However, the two garlic varieties responded differently to applied P rates. Compared to unfertilized (P1) treatment, 'Balady' plants fertilized with P2 and P3 rates had significantly higher bulb yield and mean bulb weight than 'Northern White' variety. The variation in external P requirements is mainly due to either higher uptake efficiency of the crop (cultivar/variety) or lower internal P needs for optimal growth[37]. Mulatu et al.[38] evaluated the effects of P fertilizer application on the production performance of two garlic varieties Local ('farmers' variety) and Tsedey 92 and found that bulb yields of Local and Tsedey 92 cultivars enhanced at the highest applied P fertilizer rate (45 P ha^{-1}) by 176% and 65% over control treatment, respectively.

In terms of mineral contents in garlic cloves, the results of this study revealed that the maximum contents of nutrients (P, K, and Mg) in produced garlic cloves were generally attained with application of P3, whereas, the maximum contents of the nutrients N and Ca were generally recorded at the P2 rate in both garlic varieties. The differences in garlic clove N, P, K, Ca, and Mg contents observed here might be attributed to the enhancing effect due to the essential role of phosphorus that could stimulate root growth and plant development, which promote the uptake of other mineral nutrients and consequently accumulation in garlic plant parts (cloves)[19]. Similar results have been reported by many researchers on different *Allium* crops when N, P, and K contents increased with an adequate supply of P in soil rhizosphere[18,19,24,39−41].

However, the two garlic varieties responded differently to applied P fertilizer rates with regard to nutrient content in produced garlic cloves. Cloves of 'Balady' variety had generally higher contents of N, P, K and Mg than 'Northern White' variety regardless of P rate, while 'Northern White' variety had significantly higher Ca than 'Balady' variety at the P2 rate. These results were in good accordance with those obtained by different researchers who reported that crop varieties showed different responses to P fertilization in terms of their mineral nutrient uptake and consequently the accumulation of minerals in garlic cloves[41−44].

Phosphorus supply affects growth and secondary metabolites in plants such as phenolics, flavonoids and allicin contents[19,24,25]. In this study, the response of total phenols, flavonoids and allicin contents and antioxidant activity in cloves of both garlic varieties to different rates of soil P fertilization in alkaline soil was not linear; the highest phenols, flavonoids and antioxidants values were at the P2 rate, while highest allicin content values were obtained at P3 rate. These results might indicate that the garlic response to P fertilizer application increment at calcareous soil is unique in terms of secondary metabolites accumulation. Pontigo et al.[26] found a strong relationship between phenol accumulation in plants and P efficiency (the effectiveness of uptake and internal utilization of P).

However, the two garlic varieties responded differently to applied P rates regarding total phenols, flavonoids, and allicin contents and antioxidant activity regardless of the applied P rate. Flavonoid contents and antioxidant activity were significantly higher in cloves of 'Balady' than 'Northern White' variety at the P2 rate, while no significant difference was noted for total phenols contents between 'Balady' and 'Northern White' variety at both P2 and P3 rates. Allicin contents were higher in 'Balady' than 'Northern White' variety regardless of applied P rate. The enhancement due to P fertilizer application in flavonoids contents and antioxidant activity was more pronounced in 'Balady' than 'Northern White' variety at the P2 rate, while it was higher for total phenols content in 'Northern White' than in 'Balady' variety at both P2 and P3 rates.

Overall, increasing garlic yield by applying a high P level (P3) can lead to a significant negative impact on cloves' chemical composition; total phenols and flavonoids contents and antioxidant activity. Therefore, moderate P levels (P2) might be the best P rate for garlic when it is used for the development of functional food. The results of this study suggest that the bulb yield and the nutritional quality of garlic cloves differed with different rates of applied P fertilization and selection of cultivar/variety under calcareous soil conditions.

Conclusions

Phosphorus deficiency is critical for garlic production in arid and semiarid regions, especially when cultivated in calcareous soils. In this study, P fertilization significantly affected garlic growth (plant height), bulb yield (bulb yield, mean bulb weight, and clove number per bulb) and cloves chemical composition (phenolic compounds, minerals and allicin contents) of both tested varieties grown under calcareous soils. Application of P fertilizer at the high rate (P3) showed particularly high potential with respect to the high garlic yields and high P, K and Mg and allicin contents, while had high contents of nutrients N and Ca, total phenols and flavonoids and antioxidant activity at the medium rate (P2) in the cloves of both tested garlic varieties.

Although 'Balady' variety had a generally higher bulb yield, mean bulb weight, and clove number per bulb, clove N and P, flavonoid contents and antioxidant activity than in 'Northern White' variety in response to P fertilizer application, the 'Northern White' variety was more responsive to P fertilizer application by generally enhancing clove Ca content than in 'Balady' variety. Therefore, results of this study suggest that the bulb yield and nutritive quality of garlic cloves differed with different rates of applied P fertilization and selection of cultivar/variety under calcareous soil conditions.

Author contributions

The authors confirm contribution to the study paper as follows: study conception and experiment design, data collection, statistical analysis: Al-Karaki, G, Othman Y; draft manuscript preparation: Al-Karaki G, Othman Y; reviewing and refining the manuscript: Altuntas O. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Food of Agriculture Organization of the United Nations (FAO). 2020. *Crops and livestock products*. (Accessed 15 June 2024). www.fao.org/faostat/en/#data/QCL.
2. Teshale M, Tekeste N. 2021. Growth and yield response of garlic (*Allium Sativum* L.) to intra-row spacing and variety at selekeleka, northern Ethiopia. *Open Biotechnology Journal* 15:1−11
3. Chen S, Shen X, Cheng S, Li P, Du J, et al. 2013. Evaluation of garlic cultivars for polyphenolic content and antioxidant properties. *PLoS ONE* 8(11):e79730
4. Shang A, Cao SY, Xu XY, Gan RY, Tang GY, et al. 2019. Bioactive compounds and biological functions of garlic (*Allium sativum* L.). *Foods* 8:246
5. Agarwal KC. 1996. Therapeutic actions of garlic constituents. *Medicinal Research Reviews* 16:114−24
6. Slusarenko AJ, Patel A, Portz D. 2008. Control of plant diseases by natural products: allicin from garlic as a case study. *European Journal of Plant Pathology* 121:313−22
7. Rahman MS. 2007. Allicin and other functional active components in garlic: health benefits and bioavailability. *International Journal of Food Properties* 10:245−68
8. Kilgori M, MagaJi M, Yakubu A. 2007. Productivity of two garlic (*Allium sativum* L.) cultivars as affected by different levels of nitrogenous and phosphorous fertilizers in Sokoto, Nigeria. *American-Eurasian Journal of Agricultural & Environmental Sciences* 2(2):158−62
9. Durak İ, Kavutcu M, Aytaç B, Avci A, Devrim E, et al. 2004. Effects of garlic extract consumption on blood lipid and oxidant/antioxidant parameters in humans with high blood cholesterol. *The Journal of Nutritional Biochemistry* 15(6):373−77
10. Büll LT, Costa MCG, Novello A, Fernandes DM, Bôas RLV. 2004. Doses and forms of application of phosphorus in vernalized garlic. *Scientia Agricola* 61:516−21

11. Marsic NK, Necemer M, Veberic R, Ulrih NP, Skrt M. 2019. Effect of cultivar and fertilization on garlic yield and allicin content in bulbs at harvest and during storage. *Turkish Journal of Agriculture and Forestry* 43:414–29
12. Al-Karaki GN. 2002. Field response of garlic inoculated with arbuscular mycorrhizal fungi to phosphorus fertilization. *Journal of Plant Nutrition* 25:747–56
13. El-hamady MM. 2017. Growth and yield of onion *Alum cepa* L. as influenced by nitrogen and phosphorus fertilizers levels. *Canadian Journal of Agriculture and Crops* 2:34–41
14. Hopkins B, Ellsworth J. 2005. Phosphorus availability with alkaline/calcareous soil. *Western Nutrient Management Conference* 6:88–93
15. Menzies N. 2009. *The science of phosphorus nutrition: forms in the soil, plant uptake, and plant response*. Grains Research and Development Corporation, Australia. (Accessed June, 2024). https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2009/02/the-science-of-phosphorus-nutrition-forms-in-the-soil-plant-uptake-and-plant-response
16. Barrow NJ. 2017. The effects of pH on phosphate uptake from the soil. *Plant and Soil* 410:401–10
17. Yaso IA, Abdel-Razzak HS. 2007. Effect of NPK fertilization on bulb yield and quality of onion under reclaimed calcareous soil conditions. *Journal of Agricultural and Environmental Sciences* 6(1):225–44
18. Diriba-Shiferaw G, Nigussie-Dechassa R, Kebede W, Getachew T, Sharma JJ. 2013. Growth and nutrients content and uptake of garlic (*Allium sativum* L.) as influenced by different types of fertilizers and soils. *Science, Technology and Arts Research Journal* 2(3):35–50
19. Jitarwal OP, Choudhary MR, Choudhary ALOR, Yadav GL. 2018. Effect of phosphorus levels on growth, yield and quality of garlic (*Allium sativum* L.). *International Journal of Chemical Studies* 6:1816–19
20. Ruiz R. 1985. Nitrogen and phosphorus absorption rhythm and NP fertilization response in garlic. *Agricultura Técnica* 45:153–58
21. Waterer D, Schmitz D. 1994. Influence of variety and cultural practices on garlic yields in Saskatchewan. *Canadian Journal of Plant Science* 74(3):611–14
22. Zhao C, Wang Z, Cui R, Su L, Sun X, et al. 2021. Effects of nitrogen application on phytochemical component levels and anticancer and antioxidant activities of *Allium fistulosum*. *Peer J* 9:e11706
23. Serri F, Souri MK, Rezapanah M. 2021. Growth, biochemical quality and antioxidant capacity of coriander leaves under organic and inorganic fertilization programs. *Chemical and Biological Technologies in Agriculture* 8:33
24. Nell M, Vötsch M, Vierheilig H, Steinkellner S, Zitterl-Eglseer K, et al. 2009. Effect of phosphorus uptake on growth and secondary metabolites of garden sage (*Salvia officinalis* L.). *Journal of the Science of Food and Agriculture* 89:1090–96
25. Wang C, Lv J, Xie J, Yu J, Li J, et al. 2021. Effect of slow-release fertilizer on soil fertility and growth and quality of wintering Chinese chives (*Allium tuberm* Rottler ex Spreng.) in greenhouses. *Scientific Reports* 11:8070
26. Pontigo S, Ulloa M, Godoy K, Nikolic N, Nikolic M, et al. 2018. Phosphorus efficiency modulates phenol metabolism in wheat genotypes. *Journal of Soil Science and Plant Nutrition* 18:904–20
27. Turk MA, Tawaha AM. 2001. Influence of rate and method of phosphorus placement to garlic (*Allium sativum* L.) in a Mediterranean environment. *Journal of Applied Horticulture* 3:115–16
28. Al-Karaki GN, Ereifej KI. 1999. Relationships between seed yield and chemical composition of field peas grown under semi-arid Mediterranean conditions. *Journal of Agronomy and Crop Science* 182(4):279–84
29. Jordanian Ministry of Agriculture. 2016. *Annual statistical report*. Amman, Jordan
30. Bremner JM, Mulvaney CS. 1982. *Nitrogen—Total*. In: *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties, 9.2.2, Second Edition*, ed. Page AL. Madison, USA: American Society of Agronomy. pp. 595–624. doi: 10.2134/agronmonogr9.2.2ed.c31
31. Llorach R, Martínez-Sánchez A, Tomás-Barberán FA, Gil MI, Ferreres F. 2008. Characterization of polyphenols and antioxidant properties of five lettuce varieties and escarole. *Food Chemistry* 108:1028–38
32. Singleton VL, Rossi JA Jr. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16:144–58
33. Jia Z, Tang M, Wu J. 1999. The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry* 64:555–59
34. Brand-Williams W, Cuvelier ME, Berset C. 1995. Use of a free radical method to evaluate antioxidant activity. *LWT - Food Science and Technology* 28:25–30
35. Prati P, Henrique CM, de Souza AS, da Silva VSN, Pacheco MTB. 2014. Evaluation of allicin stability in processed garlic of different cultivars. *Food Science and Technology* 34:623–28
36. Shafeek MR, Nagwa MKH, Singer SM, El-Greadly NHM. 2013. Effect of potassium fertilizer and foliar spraying with Etherel on plant development, yield and bulb quality of onion plants (*Allium cepa* L). *Journal of Applied Sciences Research* 9:1140–46
37. Föhse D, Claassen N, Jungk A. 1988. Phosphorus efficiency of plants. *Plant and Soil* 110:101–09
38. Mulatu A, Tesfaye B, Getachew E. 2014. Growth and bulb yield garlic varieties affected by nitrogen and phosphorus application at Mesqan Woreda, South Central Ethiopia. *Sky Journal of Agricultural Research* 3(11):201–07
39. Brewster JL. 2008. *Onions and other vegetable Alliums*, 2nd edition. London, UK: Biddles Ltd. doi: 10.1079/9781845933999.0000
40. Abdissa Y, Tekalign T, Pant LM. 2011. Growth, bulb yield and quality of onion (*Allium cepa* L.) as influenced by nitrogen and phosphorus fertilization on vertisol I. growth attributes, biomass production and bulb yield. *African Journal of Agricultural Research* 6:3252–58
41. Majumdar B, Venkatesh MS, Kumar K, Patiram P. 2003. Response of garlic (*Allium sativum* L.) to phosphorous and Sulphur application in acid Alfisol of Meghalaya. *Journal of Spices and Aromatic Crops* 12(2):183–86
42. Novo J Junior, Ribeiro RMP, Chaves AP, de Fatima Lima Sousa V, Grangeiro LC, et al. 2016. Effect of phosphorus fertilization on yield and quality of onion bulbs. *African Journal of Agricultural Research* 11(45):4594–99
43. Zaki MF, Habib HAM, Abd El-Samad EH, Lashine ZA. 2011. Effect of different sources and rates of phosphorus on vegetative growth, antioxidant and mineral contents of two sweet fennel cultivars. *European Journal of Scientific Research* 51:499–511
44. Mohsen AM. 2012. *Response of garlic plant to nitrogen, phosphorus, potassium and some biofertilizer levels under sandy soil conditions*. Thesis. Zagazig University, Egypt