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Research article

The influence of potassium nanoparticles as a foliar fertilizer on onion growth, production, chemical content, and DNA fingerprint

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A B S T R A C T

Potassium is an important macro-fertilizer for plant growth but can be lost from the soil after application via irrigation. Slow-release nano-fertilizers can achieve sustainable crop cultivation and production, so this study evaluated the influence of potassium nanoparticles (K-NPs) with various concentrations (0, 50, 100, and 200 mg/l) on onion development, production, pigments, chemical content, and DNA fingerprint during two sequential agriculture seasons in 2021 and 2022 at a private farm in Zagazig, Sharkia Governorate, Egypt. Spraying onion plants with K-NPs (200 mg/l) significantly improved the vegetative characteristics of onion plant growth and production, as well as increasing the plant pigments and the content of carbohydrate, oil, total indole, and phosphorus in onion bulbs. Similarly, 50 mg/l of K-NPs considerably increased the content of nitrogen, potassium, protein, antioxidant activity, and phenols in the onion bulbs. The content of total flavonoids and anthocyanin was increased with 100 mg/l of K-NPs. In conclusion, the foliar application of K-NPs improves the onion plant yield and quality and can achieve agricultural sustainability.

1. Introduction

The onion belongs to the Alliaceae family and is cultivated worldwide as an important food crop. It is used for its distinctive relish or potential to improve the relish of different foods [1]. It also consists of medical and veracity-reinforcing flavonoids, fructooligosaccharides, anthocyanins, organic sulfur components, and vitamins [2,3], as well as quercetin, a prominent and significant antioxidant in cancer treatment [4,5]. These and other combinations confer onion its healing properties.

Fertilizers are typically used in food production to increase crop yield but can have detrimental ecological effects, so an alternative is the utilization of nano-fertilizers [6–8] which can boost absorption capacity by ~19 % compared to traditional fertilizers [9]. Nano-fertilizers promote plant development and production [10,11], and are easily transported into cells due to their small size where they impact various metabolic and physiological processes [12]. Nano-fertilizers reduce the amount of fertilizer applied and environmental pollution and ameliorate the bioavailability of plant nutrients [13–16]. Additionally, foliar spraying of micro and macronutrients is favorable for the rapid uptake of the nutrients required by the plant for growth [17,18].

Potassium nanoparticles (K-NPs) improve plant growth and production because potassium enhances nutrient transport,

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photosynthesis, protein composition, water poise, and enzymatic activity within the plant [19]. It is necessary for sugar translocation and carbohydrate production thus the onion plant must have appropriate quantities and provenance of potassium during the stringent growth stages to maintain development and quality [3,20]. Additionally, the onion plant has intensive roots and a prolonged growing time, thus it requires twice as much fertilizers and essential elements as much as other vegetable crops [4]. Furthermore, potassium promotes the volume of *Allium cepa* L. and root development [1]. Abd El-Aziz et al. [21] reported that potassium carboxylate application based on cellulose nano-fibers as a nano foliar fertilizer increased onion production and enhanced the content of nutrients, photosynthetic pigments, protein, phenols, indoles, total soluble solid, lignin and cellulose. Ali et al. [22] also found that the foliar spraying of nano NPK at a rate of 6 L/fedaan on onion plant cv Giza 6 gave the best values of plant length and production, while the maximum values of total exportable bulbs were gained using 75 % mineral fertilization and splattering with NPK nanoparticles at a rate of 6 L/fedaan. Therefore, potassium is imperative for onion yield and quality [23].

Considering the importance of the Relative Afferent Pupillary Defect (RAPD) and Inter Simple Sequence Repeat (ISSR) markers for the study of genetic diversity in plants [24–26]. Usually, DNA markers are used to differentiate diverse populations and genetic differences. For example, ISSR primers were used to illustrate the relationship and similarity among different sunflower cultivars, showing that primers HB-13 and HB-15 displayed the maximum polymorphism [27]. In addition, DNA markers can also be used to study the effect of the applied compounds on a molecular basis [28]. ISSR molecular markers were used to determine the molecular changes due to the application of the proline or glycine betaine on *Cicer* arietinum [29] and chemical mutagenesis by NaN_3 in *Olea europaea* l [30]. Furthermore, gene expression is affected by nano-fertilizers. Ghosh et al. [31] observed that high concentrations of ZnO-NPs increase chromosome aberrations in *Allium cepa* and cause DNA strand breaks. Also, higher application of P-NPs in sweetcorn [32], Ag-NPs in the tomato [33], and ZnO-NPs in the broad bean plant [34] affect the Genomic Template Stability percentage (GTS%).

Since potassium is an important nutrient for high-quality onion plants, this paper aims to produce potassium in nanoform for application to onion plants and investigate its effects on onion production in comparison with conventional fertilizer to achieve sustainable agriculture.

2. Material and methods

2.1. Materials

Citric acid, potassium nitrate (KNO_3), and ferric nitrate ($Fe(NO_3)_3.5H_2O$) were obtained from Sigma Aldrich. Ethanol and ethylene glycol were obtained from S.D. Fine-Chem, India. Calcium superphosphate (15.5 % P_2O_5), ammonium sulfate (20.6 % N), and agricultural sulfur were purchased from Al-Nasr Company, Egypt.

2.2. Preparation of potassium ferrite nanoparticles (K-NPs)

The synthesis of K-NPs was performed by the sol-gel method [35]. Briefly, potassium nitrate solution (1 M) and ferric nitrate solution (2 M) were mixed after that citric acid solution (2 M) and 5 ml of ethylene glycol were added. The previous solution was heated at 80 ± 5 °C under constantly magnetically stirring till a very viscous brown gel was obtained. On further heating, the gel was completely converted to a brown-colored powder. The powder was cleaned from unreacted materials using ethanol and distilled water and then dried overnight at 60 °C in a vacuum oven. The powder was calcined at 550 °C for 2 h, yielding K-NPs as the final product.

2.3. Characterization

The morphological characters of K-NPs were demonstrated by using a transmission electron microscope (TEM; model JEM-1230, Japan) that was operated at 120 kV, with a maximum magnification of 600×10^3 and a resolution of 0.2 nm. The XRD patterns were carried out on a Diano X-ray diffractometer using a CoKα radiation source energized at 45 kV and a Philips X-ray diffractometer (PW 1930 generator, PW. 1820 goniometer) with CuK radiation source (λ = 0.15418 nm). The average particle size distribution of K-NPs was determined by using a particle size analyzer (Nano-ZS, Malvern Instruments Ltd., UK).

Table 1
Characteristics of the empirical soil in Sharqia governorate, Egypt (Collective data of two seasons).

Physical characteristics					
Texture	Clay	Silt	Sand	EC (ds/m)	pH
	(%)				
Clay	56.2	32.3	11.6	0.46	7.49
Chemical characteristics					
Cations (meq/l)			**Anions (meq/l)**		
Ca	**Mg**	**Na**	**SO_4**	**CL**	**HCO_3**
2.19	0.68	1.15	3.36	1.18	1.40
Macronutrient			**Micronutrient (mg/kg)**		
N (meq/l)	**P (mg/l)**	**K (mg/l)**	**Zn**	**Fe**	**Mn**
47.2	26.5	386	1.16	5.9	0.30

2.4. Experiment layout

Onion seeds (*Allium cepa* L. cv. Giza red) were gained from the Onion Research Department, Agricultural Research Center, Ministry of Agricultural and Land Reclamation, Egypt. The onion seeds were planted on 2nd October and the acquired seedlings were acquired on 2nd December during two seasons (2021 and 2022). The plants are planted on plots (4 m long × 80 cm wide) divided into 3 rows/ridges, the distance between the plants is 10 cm. The trial work was conducted in clay soil at a private farm in Zagazig, Sharkia Governorate, Egypt (latitude 30° 57′ 65″ N, longitude 31° 50′ 41″ E, and altitude of 16 m above sea level). The physical and chemical characteristics of the studied soil (Table 1) were tested according to Cottenie et al. [36]. Organic manures (47.6 m^3/ha) were supplemented during the soil elaboration with calcium superphosphate (714 kg/ha) and agricultural sulfur (119 kg/ha). Ammonium sulfate (285.6 kg/ha) was introduced twice after one and two months from sowing.

2.5. Experiment design

Two potassium sources (KNO_3 and K-NPs) were used at concentrations of 0, 50, 100, and 200 mg/l. After 30 and 60 days from planting, different sources of K were applied twice as a foliar application on onion plants. The experiment was arranged as a split-plot scheme with three repetitions. Main plots settled the types of K however the concentrations of K were ordered systemically in the sub-plots.

2.6. Vegetative growth standards

Five onion plants from each replicate from every treatment were randomly taken at the vegetative stage after 70 days from planting to estimate the vegetative growth as follows: plant length, number of leaves, the diameter of bulb and neck, as well as the fresh and dry weight of the plant. The plants were harvested after 150 days from planting to predestine the bulb length, the diameter of the bulb and neck, fresh and dry weight of the bulb, and yield of the bulb (t/ha).

2.7. Chemical contents

2.7.1. Photosynthetic pigments

Photosynthetic pigments were estimated from fresh onion leaves that were gathered after 70 days of agriculture in 80 % acetone according to Lichtenthaler and Wellburn [37]**.** The condensations of chlorophyll *a* (Chl. a), chlorophyll *b* (Chl. b), and carotenoid (Cart.) were gauged against a blank (80 % acetone) by UV/VIS spectrophotometer (TG 80, Germany) at 663, 644, and 452 nm, consecutively Metzner et al. [38]. The pigment content was evaluated as (μg/ml) and calculated by the equations glimpsed by Jiang et al. [39]. The content of chlorophyll and carotenoids was calculated based on mg/g fresh weight of the leaves of the plants.

2.7.2. Biochemical contents

The samples of fresh onion bulbs were dehydrated at 60 °C in the oven till fixed weight and then ground for analysis. Total carbohydrates were estimated according to Dubois et al. [40]. Protein content was measured by the Kjeldahl method N × 6.25 [41]**.** The oil percentage was assessed by using the Soxhlet device that corresponded with the method mentioned in AOAC [42], and antioxidant activity was determined utilizing the 2,2-Diphenyl-2-picrylhydrazyl (DPPH) method as described by Brand-Williams et al. [43] and calculated as μmol Trolox per g dry weight. Total phenols were evaluated by UV/VIS spectrophotometer according to Diaz and Martin [44], gallic acid (GA) was utilized as the standard for analyzing total phenols as mg GA similar per gram of dried weight (mg GA/g DW). Total flavonoids were appreciated using the method reported by Chang and Wen [45], total flavonoids were evaluated as mg quercetin equivalent per gram of dry weight tissue (mg QCE/g DW). Total indoles were determined by Glickman and Dessaux [46]**,** and the content of indoles was stated as mg Indole 3-acetic acids equal per gram of dry weight (mg IAA/g DW). The content of anthocyanin was spectrophotometrically analyzed according to Gallik [47]. The anthocyanin content was expressed as mg cyanidin chloride equivalent per gram of dry weight tissue (mg CYE/g DW).

2.7.3. Minerals assessment

Dried bulb samples were pulverized and digested using H_2SO_4–H_2O_2. The focus of phosphorus and potassium was evaluated by spectrophotometer, while nitrogen was gauged by the Kjeldahl method [41,48].

Table 2
ISSR primers and their sequences used in this study.

	Primer Code	Primer Sequence
1	14 A	$(CT)_8$ TG
2	44 A	$(CT)_8$ AC
3	HB 12	$(CAC)_3$ GC
4	HB 14	$(CTC)_3$ GC
5	HB 15	$(GTG)_3$ GC

2.8. Extraction of DNA and PCR

From young leaves of treated *Allium* plants, DNA was isolated using the modified CTAB method [49]. A total of 10 ISSR primers were tried, but 5 ISSR primers with positive results Table 2 were used in this study to determine the molecular differences or variations between treated *Allium cepa* plants. Moreover, the primers were chosen after initial screening of more than 10 different primers, based on the production of distinct and reproducible bands in PCR reactions. To perform PCR-based analysis, the Polymerase chain reaction (PCR) was carried out within 15 μl reaction volumes. containing 1 μl plant genomic DNA, 7.5 μL Master Mix (Gene Direx one PCRTM), 1 μL template DNA, and 1 μL primer.

PCR was programmed as: an initial denaturation at 94 °C for 5 min, 35 cycles each of 94 °C for 1 min, 37 °C for 1 min, 72 °C for 2 min, and a final extension at 72 °C for 10 min. Amplification products were electrophoresed on 1.5 % agarose in 1 × TAE buffer. Then gel was stained with ethidium bromide and documented using a gel documentation system.

The amplified DNA amplicons using the ISSR-marker were classified as absent **(−)** or present **(+).** Initially, the total number of bands (TB), polymorphic bands (PB), and percentage polymorphism (PPB) were calculated. Polymorphism percentage (PB%) was calculated according to equation (Eq. 1):

$$PB\% = \frac{UB + PB}{\text{Total bands}} \quad \text{(Eq. 1)}$$

Where: UB is the number of unique bands and PB is the number of polymorphic bands.

2.9. Statistical analysis

The acquired data were imputed for statistical analysis of variance and resolved for significant variations using LSD by performing a 5 % level of differentiation steps according to Snedecor and Cochran [50].

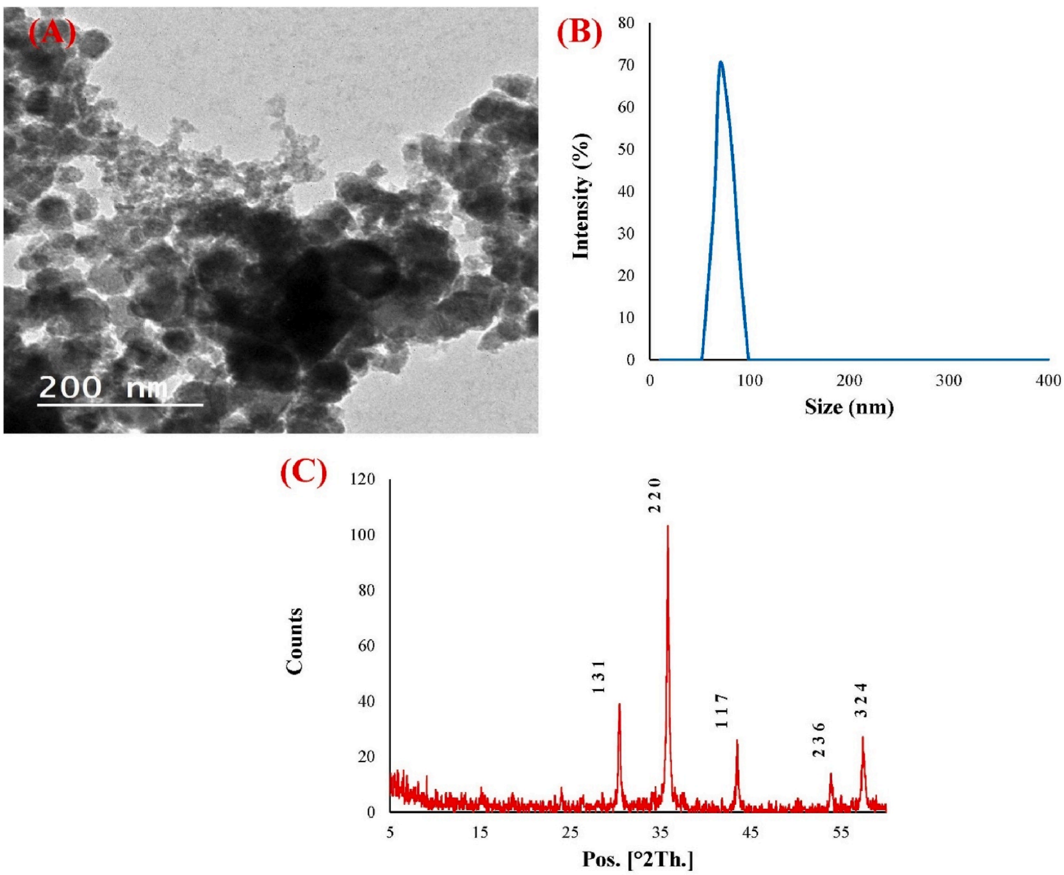

Fig. 1. TEM image (A), particle size distribution (B), and XRD partum (C) of K-NPs.

3. Results

3.1. Potassium ferrite nanoparticles (K-NPs) characterization

The K-NPs morphological structure in Fig. 1a shows that the nanoparticles are symmetric spheres less than 100 nm in size, with an average particle size of 78 nm (Fig. 1b). Fig. 1c presents the K-NPs XRD diffraction pattern with peaks visible at 2θ equal 30.4°, 35.7°, 43.5°, 54°, and 57.4°, respectively, corresponding to the crystal planes (1 3 1), (2 2 0), (1 1 7), (2 3 6) and (3 2 4), which shows that K-NPs were properly formed.

3.2. Vegetative growth

The onion plants sprayed with K-NPs data displayed significantly superior vegetative growth characteristics such as plant length (70.0 and 67.7 cm), number of leaves (7.9 and 7.4), diameter of bulb (2.58 and 2.49 cm) and neck (1.73 and 1.72 cm), and fresh (87.1 and 80.8 g/plant) and dry plant weight (8.2 and 7.7 g/plant) compared to KNO_3 during the planting seasons 2021 and 2022 (Table 3).

Data recorded in Table 3 showed obviously that different concentrations augmented significantly vegetative growth characteristics of onion plants. The highest concentration of K-NPs (200 mg/l) improved plant length (73.1 and 69.7 cm), number of leaves (8.3 and 7.7), diameter of bulb (2.80 and 2.2.61 cm) and neck (1.90 and 1.87 cm), and fresh (94.9 and 88.0 g/plant) and dry weight (9.8 and 8.9 g/plant), during two consecutive seasons 2021 and 2022.

The interaction between K-type and its concentrations had a significant impact on the vegetative growth of the onion plant as shown in Table 3, through sequential seasons 2021 and 2022. The best plant length (73.1 and 70.6 cm), number of leaves (8.3 and 7.7), the diameter of bulb (2.93 and 2.79 cm) and neck (2.03 and 2.00 cm), and fresh (105.7 and 95.4 g/plant) and dry weight (9.8 and 8.9 g/plant) of onion plants was achieved with plants sprayed by K-NPs at a concentration of 200 mg/l compared with other treatments, during two successive seasons 2021 and 2022.

Table 3
Effect of KNO_3, $KFeO_2$-NPs, their concentrations and their interaction on vegetative growth characteristics of onion plants during two seasons 2021 and 2022.

Treatments	Concentrations (mg/l)	Plant length (cm)		No. of leaves /Plant		Diameter (cm) Bulb		Neck		Plant weight (g) Fresh		Dry	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
KNO_3	**0**	64.7 ± 5.51	63.3 ± 3.51	7.7 ± 0.58	7.4 ± 0.35	2.03 ± 0.15	1.95 ± 0.05	1.50 ± 0.10	1.45 ± 0.06	62.7 ± 2.39	60.4 ± 1.51	6.3 ± 0.24	6.0 ± 0.15
	50	68.8 ± 5.30	66.1 ± 4.11	7.3 ± 0.53	7.0 ± 0.145	2.47 ± 0.15	2.34 ± 0.15	1.70 ± 0.10	1.64 ± 0.06	80.5 ± 3.81	77.3 ± 4.46	6.5 ± 0.31	6.4 ± 0.15
	100	71.2 ± 4.80	670.± 1.10	7.7 ± 1.00	7.1 ± 0.92	2.50 ± 0.46	2.38 ± 0.44	1.73 ± 0.06	1.68 ± 0.05	81.5 ± 5.57	78.8 ± 3.24	7.4 ± 0.36	7.1 ± 0.31
	200	72.3 ± 1.15	68.7 ± 3.84	8.0 ± 0.58	7.4 ± 0.17	2.67 ± 0.45	2.43 ± 0.45	1.77 ± 0.15	1.74 ± 0.06	84.1 ± 5.22	80.5 ± 6.79	7.8 ± 0.56	7.5 ± 0.55
Mean		**69.2**	**66.3**	**7.7**	**7.2**	**2.42**	**2.27**	**1.68**	**1.63**	**77.2**	**74.2**	**7.0**	**6.8**
K-NPs	**0**	64.7 ± 5.51	63.3 ± 3.51	7.7 ± 0.58	7.4 ± 0.35	2.03 ± 0.15	1.95 ± 0.05	1.50 ± 0.10	1.45 ± 0.06	62.7 ± 2.39	60.4 ± 1.51	6.3 ± 0.24	6.0 ± 0.15
	50	69.0 ± 8.19	66.7 ± 3.15	7.0 ± 0.58	6.8 ± 0.80	2.63 ± 0.21	2.62 ± 0.36	1.73 ± 0.06	1.65 ± 0.05	87.0 ± 6.08	81.5 ± 4.78	8.1 ± 0.60	7.6 ± 0.64
	100	72.5 ± 2.78	70.0 ± 1.66	8.3 ± 0.58	7.4 ± 0.35	2.73 ± 0.47	2.62 ± 0.42	1.83 ± 0.12	1.77 ± 0.06	89.9 ± 4.50	85.8 ± 3.92	8.6 ± 0.61	8.3 ± 1.10
	200	73.8 ± 4.19	70.6 ± 7.64	8.7 ± 1.00	8.1 ± 0.48	2.93 ± 0.21	2.79 ± 0.20	2.03 ± 0.23	2.00 ± 0.19	105.7 ± 5.51	95.4 ± 4.41	9.8 ± 0.49	8.9 ± 0.50
Mean		**70.0**	**67.7**	**7.9**	**7.4**	**2.58**	**2.49**	**1.78**	**1.72**	**86.3**	**80.8**	**8.2**	**7.7**
Mean	**0**	64.7	63.3	7.7	7.4	2.03	1.95	1.50	1.45	62.7	60.4	6.3	6.0
	50	68.9	66.4	7.2	6.9	2.55	2.48	1.72	1.66	83.8	79.4	7.3	7.0
	100	71.8	68.5	8.0	7.2	2.62	2.50	1.78	1.72	85.7	82.3	8.0	7.7
	200	73.1	69.7	8.3	7.7	2.80	2.61	1.90	1.87	94.9	88.0	8.8	8.2
LSD 5 %	**K - type**	**2.56**	**2.69**	**0.62**	**0.92**	**0.88**	**0.91**	**0.22**	**0.12**	**7.74**	**7.29**	**0.42**	**0.67**
	Conc.	**7.14**	**5.70**	**1.07**	**0.85**	**0.36**	**0.32**	**0.14**	**0.11**	**5.27**	**4.98**	**0.54**	**0.70**
	Interaction	**10.09**	**8.06**	**1.51**	**1.20**	**0.51**	**0.46**	**0.20**	**0.15**	**7.45**	**7.04**	**0.77**	**0.99**

3.3. Yield and its components

The increment of yield characteristics of onion plants was significant with the K-types, their concentration, and their interaction through two growing seasons 2021 and 2022 (Table 4). Onion plants splashed with K-NPs presented a marked increase in yield as expressed by bulb length (5.8 and 5.6 cm), the diameter of the bulb (6.7 and 6.4 cm), and neck (2.3 and 2.2 cm), fresh (117.3 and 109.9 cm), and dry weight of the bulb (17.1 and 15.6 cm), and bulb yield (t/ha) (44.4 and 41.6 cm), respectively through two consecutive agricultural seasons 2021 and 2022 compared to KNO_3.

Concerning the influence of various concentrations on the onion plants, data in Table 4 exhibited that onion plants showed superior yield characteristics; bulb length (6.1 and 5.7 cm), the diameter of the bulb (6.9 and 6.6 cm), and neck (2.4 and 2.3 cm), fresh (131.2 and 123.8 cm), and dry weight of the bulb (22.0 and 19.1 cm), and bulb yield (49.6 and 46.8 t/ha) with the highest spray concentration of 200 mg/l on plants, during two sequential seasons 2021 and 2022, whereas the lowest values of productivity characteristics were observed with the lowest concentration.

In addition, Table 4 illustrates the interaction between the K-types and their concentrations on the productivity of the onion plant. The maximum concentration of 200 mg/l of K-NPs showed a significant response on the best yield characteristics; bulb length (6.2 and 5.9 cm), the diameter of the bulb (7.1 and 6.8 cm), and neck (2.5 and 2.4 cm), fresh (133.7 and 127.0 cm), and dry weight of the bulb (22.5 and 20.7 cm), and bulb yield (50.6 and 48.0 t/ha) compared with other treatments.

3.4. Photosynthetic pigments

The foliar application of K-NPs increased the content of photosynthetic pigments in onion leaves which is expressed as chl. A (1.441 and 1.340 mg/g), chl. B (0.580 and 0.540 mg/g), total chl. (2.210 and 1.880 mg/g), and cart. (0.631 and 0.605 mg/g) compared to KNO_3 through two sequential cultivation seasons 2021 and 2022 (Fig. 2A).

The foliar application of multiple concentrations of KNO_3 and K-NPs as shown in Fig. 2B, significantly increased the content of photosynthetic pigments (Chl. a, Chl. b, total Chl., and Cart.) in onion leaves on a fresh weight basis over two growing seasons 2021 and 2022; this increase was dose-dependent. The content of Chl. a, Chl. b, total Chl., and Cart. in the leaves of onion plant became greater at a concentration of 200 mg/l (1.583 and 1.492 mg/g), (0.620 and 0.597 mg/g), (2.204 and 2.089 mg/g), and (0.813 and

Table 4
Effect of KNO_3, K-NPs, their concentrations and their interaction on yield characteristics of onion plant during two seasons 2021 and 2022.

Treatments	Concentrations (mg/l)	Bulb length (cm)		Diameter (cm)				Bulb weight (g)				Bulb yield (t/ha)	
				Bulb		Neck		Fresh		Dry			
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
KNO_3	**0**	5.5± 0.55	5.3± 0.36	6.0 ± 0.62	5.7 ± 0.25	2.1 ± 0.07	2.0 ± 0.05	94.9 ± 4.99	88.5 ± 2.37	10.2 ± 1.11	9.3 ± 0.30	36.0 ± 1.95	33.4 ± 0.91
	50	5.4 ± 0.25	5.4 ± 0.48	6.2 ± 0.36	5.8 ± 0.21	2.2 ± 0.10	2.0 ± 0.10	96.1 ± 5.23	89.6 ± 3.46	11.7 ± 1.18	10.8 ± 0.80	36.3 ± 2.00	33.9 ± 1.33
	100	5.6 ± 0.38	5.5 ± 0.29	6.3 ± 0.26	6.0 ± 0.10	2.2 ± 0.35	2.2 ± 0.31	103.3 ± 9.29	96.4 ± 6.92	17.0 ± 2.00	14.8 ± 1.20	39.1 ± 3.52	36.4 ± 1.23
	200	6.1 ± 0.12	5.6 ± 0.23	6.6 ± 0.58	6.4 ± 0.48	2.2 ± 0.44	2.2 ± 0.41	128.7 ± 0.01	120.6 ± 2.78	21.4 ± 2.40	17.5 ± 2.00	48.6 ± 0.06	45.6 ± 1.04
Mean		**5.6**	**5.4**	**6.3**	**6.0**	**2.2**	**2.1**	**105.7**	**98.8**	**15.1**	**13.1**	**40.0**	**37.3**
K-NPs	**0**	5.5 ± 0.55	5.3 ± 0.36	6.0 ± 0.62	5.7 ± 0.25	2.1 ± 0.07	2.0 ± 0.05	94.9 ± 4.99	88.5 ± 2.37	10.2 ± 1.11	9.3 ± 0.30	36.0 ± 1.95	33.4 ± 0.91
	50	5.7 ± 0.93	5.6 ± 0.49	6.7 ± 0.79	6.4 ± 0.10	2.2 ± 0.35	2.1 ± 0.33	111.5 ± 11.81	102.6 ± 7.11	17.0 ± 1.00	15.1 ± 2.10	42.2 ± 4.45	38.8 ± 2.69
	100	5.9 ± 0.69	5.7 ± 0.59	6.9 ± 0.61	6.7 ± 0.35	2.3 ± 0.38	2.3 ± 0.31	129.1 ± 0.85	121.6 ± 1.20	18.5 ± 1.50	17.4 ± 1.60	48.8 ± 0.30	46.0 ± 0.46
	200	6.2 ± 0.42	5.9 ± 0.40	7.1 ± 0.40	6.8 ± 0.23	2.5 ± 0.38	2.4 ± 0.27	133.7 ± 3.36	127.0 ± 3.19	22.5 ± 2.50	20.7 ± 2.20	50.6 ± 1.22	48.0 ± 1.17
Mean		**5.8**	**5.6**	**6.7**	**6.4**	**2.3**	**2.2**	**117.3**	**109.9**	**17.1**	**15.6**	**44.4**	**41.6**
Mean	**0**	5.5	5.3	6.0	5.7	2.1	2.0	94.9	88.5	10.2	9.3	36.0	33.4
	50	5.6	5.5	6.5	6.1	2.2	2.1	103.8	96.1	14.4	12.9	39.2	36.3
	100	5.7	5.5	6.6	6.3	2.3	2.2	116.2	109.0	17.8	16.1	43.9	41.2
	200	6.1	5.7	6.9	6.6	2.4	2.3	131.2	123.8	22.0	19.1	49.6	46.8
LSD 5 %	**K - type**	**1.02**	**1.04**	**0.62**	**0.67**	**0.86**	**0.54**	**5.36**	**1.49**	**2.59**	**2.40**	**2.17**	**1.28**
	Conc.	**0.59**	**0.49**	**0.74**	**0.31**	**0.36**	**0.30**	**8.07**	**5.33**	**1.99**	**1.93**	**2.60**	**1.50**
	Interaction	**0.84**	**0.69**	**1.05**	**0.43**	**0.50**	**0.43**	**11.41**	**7.54**	**2.82**	**2.73**	**3.68**	**2.12**

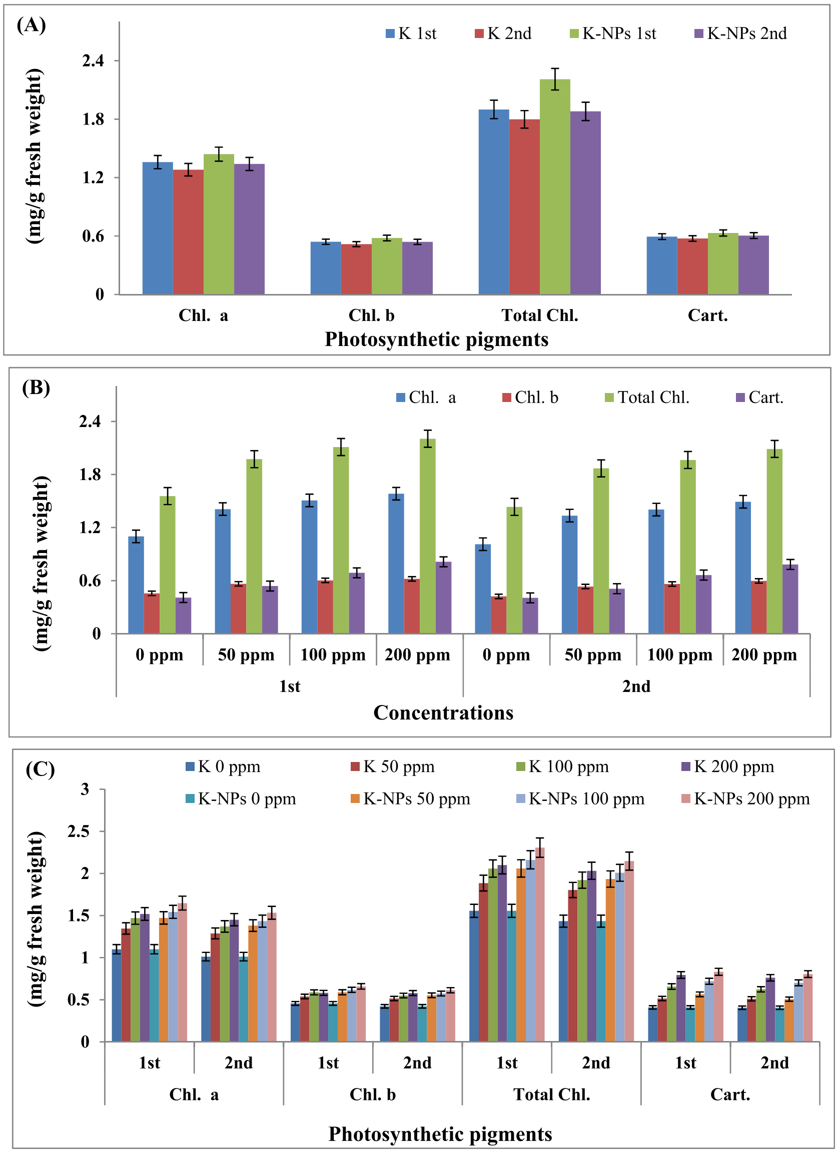

Fig. 2. Effect of KNO_3 and K-NPs (A), their concentration (B), and interaction between potassium types (C) on photosynthetic pigments of onion leaves during two seasons 2021 and 2022.

0.783 mg/g), respectively, than other concentrations during two agriculture seasons in 2021 and 2022.

The interaction between the potassium source and concentration (200 mg/l) results in the highest content of Chl. a (1.648 and 1.533 mg/g), Chl. b (0.659 and 0.613 mg/g), total Chl. (2.307 and 2.147 mg/g), and Cart. (0.832 and 0.805 mg/g) in the leaves of the onion plant (Fig. 2C) compared to other treatments through alternate seasons 2021 and 2022.

3.5. Biochemical contents

Table 5 shows the impact of K-types, their concentrations, and their interaction on the biochemical content of onion bulbs on a dry weight basis during two successive seasons of 2021 and 2022. The content of carbohydrates, protein, oil, antioxidant activity, phenols, flavonoids, indoles, and anthocyanin in onion bulbs was significantly increased by the foliar application of K-NPs, with the highest values of total carbohydrates and total indoles observed in the bulbs of plants treated with 200 mg/l K-NPs through two alternate cropping seasons 2021 and 2022. The highest content of protein, antioxidant activity, and phenols were observed at the lowest concentration of 50 mg/l, with the increment of oil, flavonoids, and anthocyanin content observed at a concentration of 100 mg/l in bulbs on a dried weight basis during sequent seasons 2021 and 2022.

The interaction between the potassium type and concentration significantly affected the biochemical content of onion plant bulbs

Table 5
Effect of KNO_3, K-NPs, their concentrations and their interaction on biochemical contents of onion bulb during two seasons 2021 and 2022.

Treatments	**Concentrations (mg/l)**	**Total** Carbohydrates **(%)**		Protein **(%)**		Oil **(%)**		Antioxidant activity (μmol Trolox **/g DW)**		Phenols (mg GA/g DW)		Flavonoids (mg QCE/g DW)		Anthocyanin **(mg CYE/g DW)**		Indoles (mg IAA/g DW)	
		2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
k	**0**	54.6 ± 1.39	53.2 ± 2.56	12.4 ± 0.06	12.0 ± 0.18	4.56 ± 1.06	4.50 ± 0.84	11.6 ± 0.46	11.1 ± 0.41	15.8 ± 0.73	15.3 ± 0.24	2.8 ± 0.44	2.6 ± 0.16	1.77 ± 0.03	1.70 ± 0.01	11.1 ± 0.46	10.5 ± 0.13
	50	51.5 ± 0.76	50.6 ± 5.17	12.2 ± 0.31	11.9 ± 0.31	3.74 ± 0.38	3.67 ± 0.22	11.9 ± 0.61	11.4 ± 0.44	17.1 ± 0.83	16.6 ± 0.26	2.4 ± 0.06	2.3 ± 0.08	1.93 ± 0.07	1.90 ± 0.02	11.0 ± 0.39	10.3 ± 0.15
	100	56.3 ± 0.78	53.2 ± 6.65	12.9 ± 0.76	12.6 ± 0.44	3.86 ± 0.27	3.71 ± 0.30	11.5 ± 1.20	11.0 ± 1.01	15.5 ± 0.66	15.1 ± 0.12	3.1 ± 0.04	3.0 ± 0.03	2.73 ± 0.09	2.65 ± 0.13	11.4 ± 0.43	10.8 ± 0.34
	200	58.5 ± 0.25	54.1 ± 1.60	12.5 ± 1.25	12.4 ± 0.62	4.00 ± 0.04	3.83 ± 0.09	10.3 ± 0.65	9.9 ± 0.42	14.1 ± 1.13	13.7 ± 0.61	2.1 ± 0.12	2.0 ± 0.10	2.57 ± 0.43	2.19 ± 0.01	12.8 ± 0.29	12.3 ± 0.39
Mean		**55.3**	**52.8**	**12.5**	**12.2**	**4.04**	**3.93**	**11.3**	**10.9**	**15.5**	**15.2**	**2.6**	**2.4**	**2.25**	**2.11**	**11.6**	**11.0**
k-NPs	**0**	54.6 ± 1.39	53.2 ± 2.56	12.4 ± 0.06	12.0 ± 0.18	4.56 ± 1.06	4.50 ± 0.84	11.6 ± 0.46	11.1 ± 0.41	15.8 ± 0.73	15.3 ± 0.24	2.8 ± 0.44	2.6 ± 0.16	1.77 ± 0.03	1.70 ± 0.01	11.1 ± 0.46	10.5 ± 0.13
	50	58.6 ± 0.38	56.9 ± 1.69	15.9 ± 0.31	15.4 ± 0.10	3.92 ± 0.17	3.85 ± 0.13	13.5 ± 0.72	12.8 ± 0.68	20.0 ± 2.48	19.7 ± 1.85	3.1 ± 0.10	2.9 ± 0.06	2.24 ± 0.04	2.14 ± 0.04	11.2 ± 0.52	10.9 ± 0.13
	100	58.9 ± 0.17	57.4 ± 1.50	14.4 ± 0.31	14.2 ± 0.41	3.94 ± 0.15	3.90 ± 0.15	12.5 ± 0.91	12.0 ± 0.74	17.2 ± 1.02	16.6 ± 0.57	3.2 ± 0.07	3.0 ± 0.04	3.04 ± 0.15	2.68 ± 0.23	12.6 ± 0.49	11.8 ± 0.63
	200	60.8 ± 0.69	58.1 ± 0.15	13.8 ± 0.06	13.3 ± 0.20	4.57 ± 0.51	4.55 ± 0.25	11.9 ± 0.43	11.4 ± 0.53	16.0 ± 1.13	14.9 ± 0.80	2.5 ± 0.42	2.5 ± 0.19	2.11 ± 0.13	2.05 ± 0.05	14.4 ± 0.35	13.4 ± 0.46
Mean		58.2	56.4	14.1	13.7	4.25	4.20	12.4	11.8	17.2	16.6	2.9	2.8	2.29	2.14	12.3	11.6
Mean	**0**	54.6	53.2	12.4	12.0	4.56	4.50	11.6	11.1	15.8	15.3	2.8	2.6	1.8	1.7	11.1	10.5
	50	55.1	53.7	14.1	13.6	3.83	3.76	12.7	12.1	18.6	18.1	2.7	2.6	2.1	2.0	11.1	10.6
	100	57.6	55.3	13.6	13.4	3.90	3.80	12.0	11.5	16.3	15.9	3.1	3.0	2.9	2.7	12.0	11.3
	200	59.7	56.1	13.2	12.8	4.29	4.19	11.1	10.7	15.1	14.3	2.3	2.2	2.3	2.1	13.6	12.8
LSD 5 %	**K - type**	**1.03**	**6.01**	**1.55**	**0.74**	**0.33**	**0.22**	**0.91**	**0.75**	**0.77**	**0.71**	**0.34**	**0.18**	**0.08**	**0.22**	**0.18**	**0.43**
	Conc.	**1.05**	**2.72**	**0.53**	**0.41**	**0.80**	**0.50**	**0.58**	**0.52**	**1.42**	**1.07**	**0.32**	**0.12**	**0.23**	**0.12**	**0.56**	**0.40**
	Interaction	**1.49**	**3.84**	**0.75**	**0.58**	**1.13**	**0.70**	**0.82**	**0.74**	**2.01**	**1.51**	**0.46**	**0.17**	**0.33**	**0.17**	**0.79**	**0.57**

(Table 5) through two farming seasons 2021 and 2022. The best protein and phenols content, and antioxidant activity in the bulbs were observed at the lowest concentration of 50 mg/l K-NPs, whereas the maximum values of total flavonoids and anthocyanin were observed at a concentration of 100 mg/l K-NPs. Additionally, the content of carbohydrates, oil, and total indoles increased in bulbs produced from the plants treated with a higher concentration of 200 mg/l of K-NPs.

3.6. Minerals

Fig. 3A shows that the K-type and concentrations as well as their interaction markedly increased the proportion of nitrogen, potassium, and phosphorus in the onion bulbs during two alternated seasons. Onion plants splattered with K-NPs had a good proportion of nitrogen (2.26 % and 2.19 %), potassium (0.33 % and 0.31), and phosphorus (1.69 % and 1.65 %) in the bulbs on a dry weight base during the two farming seasons.

Fig. 3B indicates that the mineral content of the onion bulbs reached a significant level of 5 % through the two growing seasons. The lowest concentration of 50 mg/l presented the best nitrogen content in onion bulbs, whereas the upper concentration of 200 mg/l gave a superior percentage of phosphorus in bulbs. The potassium content in onion bulbs improved with a concentration of 100 mg/l.

Fig. 3C reveals that the interaction between the potassium types and concentrations significantly impacted the content of nitrogen, potassium, and phosphorus in the onion bulbs during two successive cultivation seasons 2021 and 2022. The maximum nitrogen percentage was observed in onion plants treated with 50 mg/l K-NPs, whereas the phosphorus content in bulbs was boosted with the highest concentration of 200 mg/l K-NPs and 100 mg/l of K-NPs achieved the optimal potassium percentage in bulbs.

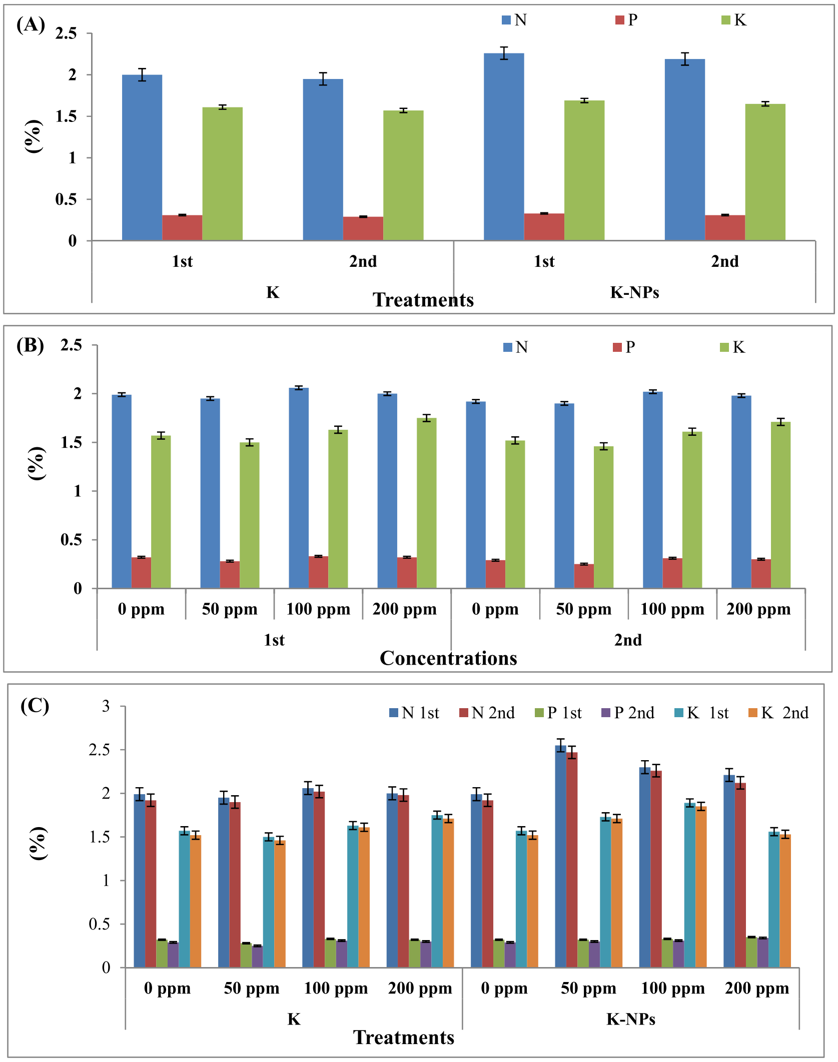

Fig. 3. Effect of KNO_3 and K-NPs (A), the concentrations of KNO_3 and K-NPs (B), as well as the interaction between K-types, and their concentrations (C) on minerals contents of onion bulb during two seasons 2021 and 2022.

3.7. ISSR-molecular markers

The effect of foliar spraying of onion plants with K and K-NPs on ISSR-markers (14 A, 44 A, HB 12, HB 14, and HB 15) was illustrated in Fig. 4. The original pictures of the gels of ISSR-markers (14 A, 44 A, HB 12, HB 14, and HB 15) were illustrated in Figs. S1, S2, S3, S4, and S5, respectively, as supplementary material. Furthermore, the recorded data in **Tables (6 and 7)** showed the effect of both potassium and its nano-particles on reproducible DNA fragments of *Allium* plants. The multiple fragments with different molecular weights were detected using these primers, and the reproducible fragments were distributed between monomorphic bands, polymorphic bands, and unique bands.

It was noticed that there were 69 bands as a total number of bands (TAF) with a polymorphism percentage average (78.99 %). Moreover, the reproducible bands were distributed as 16 MB which were detected in all treated samples, 27 PB (among some samples not all) and 26 UB (only in one sample). It was noticed that the highest level of polymorphism (87.50 %) was observed with primer HB 12, while the lowest polymorphism was 63.64 % with HB 14 primer (Table 6).

Moreover, the detected bands varied in number, polymorphism and range of their molecular weights between used ISSR primers. About primer 14 A, there were 13 reproducible bands with molecular weights ranging between (114.028–475.260 bp), moreover, it

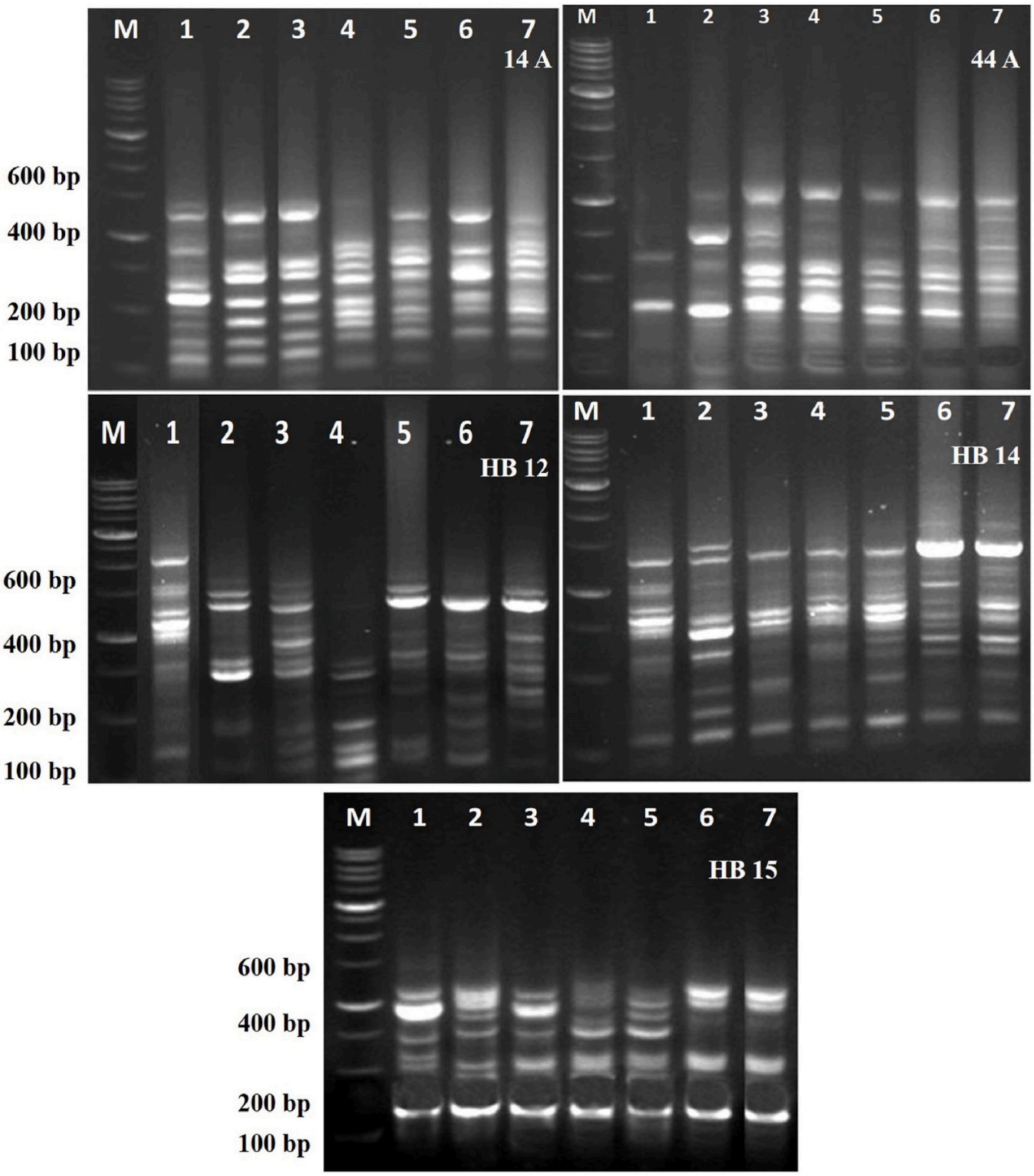

Fig. 4. Effect of foliar spraying with K and K-NPs on ISSR-markers (14 A, 44 A, HB 12, HB 14, and HB 15) of *Allium* plants. **M = DNA Marker, 1** = control; **2** = K (50 mg/l); **3** = K (100 mg/l); **4** = K (200 mg/l); **5** = K-NPs (50 mg/l); **6** = K-NPs (100 mg/l); **7** = K-NPs (200 mg/l).

Table 6
Effect of K and K-NPs on ISSR-markers of *Allium* plants.

Primers	Marker size (bp)	Amplified bands				PB %
		TAF	MB	UB	PB	
14 A	114.028–475.260	13	3	4	6	76.92
44 A	79.749–408.325	15	4	5	6	73.33
HB 12	89.385–634.300	16	2	6	8	87.50
HB 14	149.615–484.260	11	4	4	3	63.64
HB 15	135.998–545.048	14	3	7	4	78.57
Total		**69**	**16**	**26**	**27**	**-**
Average		**13.80**	**3.2**	**5.2**	**5.4**	**75.99**

TAF is the Total amplified fragments, **MB** is the Monomorphic bands, **UB** is the Unique bands, **PB** is the Polymorphic bands and **PB (%)** is the percentage of polymorphism.

was distributed as 3 MB, 4 UB, and 6 PB with 76.92 % polymorphism. Meanwhile, 15 bands with molecular weights (79.749–408.325 bp) and 73.33 % polymorphism were detected using 44 A primer and distributed as 4 MB, 5 UB, and 6 PB. However, HB 12 primer detected the highest total amplified bands (16 bands), polymorphic bands (8 bands), and polymorphism % (87.50 %), also there were 2 MB and 6 UB were detected with the same primer. Moreover, molecular weights of the detected bands using this primer (HB 12) ranged between (89.385 and 634.300 bp) as shown in Table 6.

On the other hand, the lowest total amplified bands, polymorphic bands, and polymorphism% (11 bands, 3 bands, and 63.64 %), respectively, were scored with HB 14 primer with molecular weights ranging between (149.615–484.260 bp) as found in Table 6 and Fig. 4.

Table 6 presents a general idea about the reproducible bands detected using the previous five ISSR primers. However, Table 7 draws the attention to number, size, type and conjugative reproducible bands that were detected by each primer separately. Moreover, some bands have the same molecular weight and these were called polymorphic bands and this conjunction was due to the effect of the treatments. (Table 7).

4. Discussion

The application of K-NPs (200 mg/l) as splatter fertilizer has a salutary impact on onion plant development and production (Tables 3 and 4) in line with the study of Márquez-Prieto et al. [7] that indicated that green bean plant production improved when treated with 200 ppm nano potassium, possibly due to increased cell split [51] and several enzymatic growth and activity to improve crop quality [52]. Potassium acts on the enzymes responsible for protein composition, sugar conversion, nitrogen and carbon metabolism, and photosynthesis, thereby enhancing plant productivity and quality [19,53]. Also, it is paramount for growing plant cells, which is a critical operation for plant maturity [54]. Generally, potassium activates and regulates ATPase in the plasma membrane to produce acid inducement, which then catalysts cell wall loosening and hydrolase stimulation [53], consequently strengthening cell evolution. This outcome also might be due to the increased photosynthesis pigments observed with the application of 200 mg/l K-NPs (Fig. 2) which are fundamental for photosynthesis to occur in plants [55]. Spraying of potassium nano-fertilizers promoted metabolic activities and thus increased the leaf surface area for chemical and physical activity [56,57]. Hirak et al. [58] found that the highest dose of potassium supplementation increased carbohydrate metabolism in plants. El-Mergawi and Abd El-Wahed [59] indicated that the total indole content augmented with improved plant outgrowth. Yang et al. [60] revealed that phytohormone production can be affected by nanoparticles. Similarly, El-Metwally et al. [61] reported that the percentage of total oil and protein in peanut seeds was enhanced by applying nano-fertilizer. Ricco et al. [62] revealed that nanoparticles changed the content of fatty acids, amino acids, and phenols in plants.

The subaltern metabolite output (i.e., flavonoids, phenols, antioxidants, and anthocyanin) and their content in plants were affected by nano-nutrients and their concentration [63]. Fertilizers in nano-form are easily taken up by plant cells, thereby supplying sufficient nutrients to enhance antioxidant vigor [64]. In addition, Zafar et al. [65] showed that lower NP concentrations amplified antioxidant activity, followed by a decline at higher concentrations. Flavonoids and phenolic acids are associated with antioxidant activity [66]. Similarly, Thiruvengadam et al. [67] reported that the anthocyanin output was ameliorated by treating plants with a high concentration of nanoparticles that may act as a defense against the oxidative strain caused by the NPs.

The increment of mineral content in the onion bulbs observed in this study may be due to the tardy launch of K-NPs in supplying plants with nutrients that include the preservation of metabolism and increased crop production [68]. Furthermore, the application of nano-fertilizers caused alterations in the absorption of other available nutrients in plants [69]. due to interactions in ion absorption and the transport of other metals inside the plant cells [70,71]. Also, Han et al. [72] showed that potassium is widely transported within plants and has a substantial function in cellular osmotic stress and cation/anion equilibrium in the cytoplasm.

In summary, K-NPs improve onion plant growth, production, and biochemical content due to their small size and are capable of retaining many ions due to their increasing surface area and slow release [73]. The spray application of K-NPs is more influential than the common fertilizer [74]. Moreover, plant biological responses depend on the chemical composition of the nanoparticles and concentration [11], as well as the origin, volume, focus, and time of addition to plants [75,76].

Considering the importance of molecular markers i.e.: RAPD and ISSR markers for studying the genetic relationship and diversity in

Table 7
Effect of foliar spraying with K and K-NPs on ISSR-markers of *Allium* plants.

MW	Cont.	K 50	K 100	K 200	K-NPs 50	K-NPs 100	K-NPs 200	Polymorphism
	14 A							
475.260	–	+	+	+	+	+	+	PB
383.732	–	+	–	–	–	–	–	**UB**
367.661	–	–	–	+	–	–	–	**UB**
340.807	+	–	–	–	–	–	–	**UB**
294.554	–	+	+	+	+	+	+	**PB**
276.245	–	–	–	–	+	+	+	**PB**
255.571	+	–	–	–	–	–	–	**UB**
220.886	+	+	+	+	+	+	+	**MB**
186.142	+	+	+	+	+	+	+	**MB**
156.255	–	–	–	–	+	+	+	**PB**
145.689	+	+	+	+	–	–	–	**PB**
128.390	+	+	+	+	+	+	+	**MB**
114.028	–	–	+	+	–	–	–	**PB**
44 A								
408.325	+	+	+	+	+	+	+	**MB**
332.546	–	–	–	–	+	+	–	**PB**
309.843	–	–	–	+	–	–	–	**UB**
274.562	–	+	+	–	–	–	–	**PB**
264.119	–	–	–	–	+	+	+	**PB**
213.635	+	+	+	+	–	–	–	**PB**
205.979	–	–	–	–	–	–	+	**UB**
203.643	–	–	–	–	–	+	–	**UB**
198.597	–	–	–	–	+	–	–	**UB**
165.849	+	+	+	+	+	+	+	**MB**
138.502	+	+	+	+	+	+	+	**MB**
113.832	–	–	–	–	+	+	+	**PB**
107.768	+	–	–	–	–	–	–	**UB**
94.413	–	+	+	+	–	–	–	**PB**
79.749	+	+	+	+	+	+	+	**MB**
HB 12								
634.300	–	–	–	–	+	+	+	**PB**
532.788	–	+	–	–	–	–	–	**UB**
420.207	+	+	+	+	+	+	+	**MB**
359.864	+	–	–	–	–	–	–	**UB**
329.813	–	–	–	–	+	+	–	**PB**
316.508	+	–	–	–	–	–	–	**UB**
298.633	–	–	–	–	+	–	–	**UB**
283.823	–	+	+	–	–	–	–	**PB**
263.930	–	–	–	–	+	+	+	**PB**
245.431	+	–	–	–	–	–	–	**UB**
222.229	+	+	+	+	–	–	–	**PB**
184.864	–	–	–	–	+	+	+	**PB**
142.312	+	+	+	+	+	+	+	**MB**
114.714	–	–	–	+	+	+	+	**PB**
91.577	+	+	+	+	–	–	–	**PB**
89.385	–	–	–	–	–	–	+	**UB**
HB 14								
484.260	+	–	–	–	–	–	–	**UB**
419.224	–	–	–	–	+	+	+	**PB**
410.588	+	–	–	–	–	–	–	**UB**
388.611	–	–	–	+	–	–	–	**UB**
385.160	–	–	+	–	–	–	–	**UB**
344.519	+	–	+	+	+	–	+	**PB**
279.363	+	+	+	+	+	+	+	**MB**
226.193	+	+	+	+	+	+	+	**MB**
200.231	+	+	+	+	–	–	–	**PB**
176.461	+	+	+	+	+	+	+	**MB**
149.615	+	+	+	+	+	+	+	**MB**
HB 15								
545.048	+	+	+	+	+	+	+	**MB**
428.045	–	+	–	–	–	–	–	**UB**
402.455	–	–	+	–	–	–	–	**UB**
369.179	–	–	–	–	+	+	+	**PB**
332.039	+	+	+	+	+	+	+	**MB**
280.091	+	–	–	–	+	+	+	**PB**
245.778	+	–	–	–	–	–	–	**UB**

(*continued on next page*)

Table 7 (*continued*)

MW	Cont.	K 50	K 100	K 200	K-NPs 50	K-NPs 100	K-NPs 200	Polymorphism
	14 A							
475.260	–	+	+	+	+	+	+	PB
242.767	–	–	–	–	+	–	–	**UB**
235.688	–	+	+	+	–	–	–	**PB**
205.798	+	+	+	+	+	+	+	**MB**
197.837	–	–	–	–	–	+	–	**UB**
159.640	–	–	–	–	–	–	+	**UB**
148.257	–	–	–	–	–	+	–	**UB**
135.998	+	+	+	+	+	–	–	**PB**

various genera and species of plants, very little work has been conducted on different onion varieties and cultivars [25]. So, this study evaluated the effect of foliar spraying with KNO_3 and K-NPs on onion plants via changes in the reproducible ISSR-DNA fragments as shown in **Tables (6 & 7)** and Fig. 4. However, Kesralikar et al. [77] used different ISSR primers i.e: HB 12 and HB 14 to study genetic diversity between 16 onion genotypes and reported that 66.66 % of polymorphisms were scored using both HB12 and HB14 primers. Sudha et al. [78] studied the genetic similarity and diversity between onion cultivars using 10 ISSR primers and reported that 6 primers only generated 28 variable polymorphic band patterns. Brahimi et al. [79] studied the genetic and phenotypic diversity within and between onion (*Allium cepa* L.) ecotypes in Morocco using ISSR-markers, concluding that ISSR-markers are a powerful tool in distinguishing onion ecotypes. In addition, significant associations between marker scores and phenotypic traits could be detected, representing particular importance for future breeding programmers.

5. Conclusion

The application of nano forms of fertilizers improves fertilizer efficiency by increasing diffusion into plant cells. The foliar application of K-NPs on onion plants is a perfect technique for the slow release of potassium and achieving agricultural sustainability. The application of K-NPs improved the mean onion growth, yield, and quality characteristics such as yield by 11 % and 11.5 %, total carbohydrates by 5.2 % and 6.8 %, oil by 5.1 % and 6.8 %, phenols by 10.9 and 9.2 %, as well as total indoles 6 % and 5.4 % during two seasons, respectively, compared to the traditional fertilizer (KNO_3). Future studies should evaluate the foliar application of K-NPs with other micronutrients.

Data availability statement

The data will be available on request.

CRediT authorship contribution statement

Dina M. Salama: Writing – original draft, Supervision, Formal analysis, Data curation. **Mahmoud Ahmed Khater:** Writing – review & editing, Resources, Methodology. **Mahmoud E. Abd El-Aziz:** Resources, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e31635.

References

[1] M. Bekele, Effects of different levels of potassium fertilization on yield, quality and storage life of onion (Allium cepa L.) at Jimma, Southwestern Ethiopia, J Food Sci Nutr 1 (2) (2018) 32–39.
[2] I.L. Goldman, Molecular breeding of healthy vegetables, EMBO Rep. 12 (2) (2011) 96–102, https://doi.org/10.1038/embor.2010.215.
[3] N.I. Abu El-Azm, A.A.f.H.A. Metwally, S.A.H. Abd Elhady, Onion bulb yield and quality as influenced by seed or seedling planting methods as well as potassium fertilizer forms, K2SO4 and KCl, and their combination, Scientific Journal of Agricultural Sciences 5 (1) (2023) 73–84, https://doi.org/10.21608/sjas.2023.179101.1270.
[4] B.K. Al-Amri, M.M. Alabdaly, Effect of spraying with potassium, organic fertilization and plants densities in growth and yield of onion, IOP Conf. Ser. Earth Environ. Sci. 904 (1) (2021) 012068, https://doi.org/10.1088/1755-1315/904/1/012068.

[5] A.M. Al-Khafagy, K.D. Al-Jubouri, Influence of fertilizers and organic nutrients on growth and seed yield of onion, Diyala Agricultural Sciences Journal 2 (2) (2010) 64–83.
[6] R. Raliya, V. Saharan, C. Dimkpa, P. Biswas, Nanofertilizer for precision and sustainable agriculture: current state and future perspectives, J. Agric. Food Chem. 66 (26) (2018) 6487–6503, https://doi.org/10.1021/acs.jafc.7b02178.
[7] A.K. Márquez-Prieto, A. Palacio-MáRquez, E. Sanchez, B.C. Macias-López, S. Perez-Alvarez, O. Villalobos-Cano, P. Preciado-Rangel, Impact of the foliar application of potassium nanofertilizer on biomass, yield, nitrogen assimilation and photosynthetic activity in green beans, Not. Bot. Horti Agrobot. Cluj-Napoca 50 (1) (2022) 12569, https://doi.org/10.15835/nbha50112569, 12569.
[8] A.A. Feregrino-Perez, E. Magaña-López, C. Guzmán, K. Esquivel, A general overview of the benefits and possible negative effects of the nanotechnology in horticulture, Sci. Hortic. 238 (2018) 126–137, https://doi.org/10.1016/j.scienta.2018.03.060.
[9] M. Kah, R.S. Kookana, A. Gogos, T.D. Bucheli, A critical evaluation of nanopesticides and nanofertilizers against their conventional analogues, Nat. Nanotechnol. 13 (8) (2018) 677–684, https://doi.org/10.1038/s41565-018-0131-1.
[10] J.P. Giraldo, H. Wu, G.M. Newkirk, S. Kruss, Nanobiotechnology approaches for engineering smart plant sensors, Nat. Nanotechnol. 14 (6) (2019) 541–553, https://doi.org/10.1038/s41565-019-0470-6.
[11] S. Mahmoud, D.M. Salama, M. Abd El-Aziz, Effect of chitosan and chitosan nanoparticles on growth, productivity and chemical quality of green snap bean, Biosci. Res. 15 (4) (2018) 4307–4321.
[12] P. Sheoran, S. Goel, R. Boora, S. Kumari, S. Yashveer, S. Grewal, Biogenic synthesis of potassium nanoparticles and their evaluation as a growth promoter in wheat, Plant Gene 27 (2021) 100310, https://doi.org/10.1016/j.plgene.2021.100310.
[13] F. Zulfiqar, M. Navarro, M. Ashraf, N.A. Akram, S. Munné-Bosch, Nanofertilizer use for sustainable agriculture: advantages and limitations, Plant Sci. 289 (2019) 110270, https://doi.org/10.1016/j.plantsci.2019.110270.
[14] S.H. Abd-Elrahman, Y.A.E.-G. El-Gabry, F.A. Hashem, M.F.M. Ibrahim, E.I. El-Hallous, Z.K. Abbas, D.B.E. Darwish, N.A. Al-Harbi, S.M. Al-Qahtani, N.M. Taha, Influence of nano-chitosan loaded with potassium on potassium fractionation in sandy soil and strawberry productivity and quality, Agronomy 13 (4) (2023) 1126, https://doi.org/10.3390/agronomy13041126.
[15] A.M. Elgala, S.H. Abd-Elrahman, H.S. Saudy, M.I. Nossier, Exploiting Eichhornia crassipes shoots extract as a natural source of nutrients for producing healthy tomato plants, Gesunde Pflanz. 74 (2) (2022) 457–465, https://doi.org/10.1007/s10343-022-00622-5.
[16] M.E. Abd El-Aziz, D.M. Salama, S.M.M. Morsi, A.M. Youssef, M. El-Sakhawy, Development of polymer composites and encapsulation technology for slow-release fertilizers, Rev. Chem. Eng. 38 (5) (2022) 603–616, https://doi.org/10.1515/revce-2020-0044.
[17] A.H. Noaema, H.R. leiby, A.R. Alhasany, Effect of spraying nano fertilizers of potassium and boron on growth and yield of wheat (Triticum aestivum L.), IOP Conf. Ser. Mater. Sci. Eng. 871 (1) (2020) 012012, https://doi.org/10.1088/1757-899X/871/1/012012.
[18] N.S. Ali, H.S. Rahi, A.A. Shaker, Soil Fertility. Scientific Book House, College of Agriculture, University of Baghdad, 2014, p. 88.
[19] H. Marschner, Marschner's Mineral Nutrition of Higher Plants, Academic press, 2011.
[20] S.H. Mahmoud, D.M. Salama, A.M. El-Tanahy, A.M. El-Bassiony, Effects of prolonged restriction in water supply and spraying with potassium silicate on growth and productivity of potato, Plant Archives 19 (2) (2019) 2585–2595.
[21] M.E. Abd El-Aziz, S.M.M. Morsi, D.M. Salama, M.S.A. Elwahed, E.A. Shaaban, R.E. Abou-Zeid, Modification of TEMPO-oxidized cellulose nanofibers as a source of potassium and its impact on onion plant, Carbohydrate Polymer Technologies and Applications 6 (2023) 100388, https://doi.org/10.1016/j.carpta.2023.100388.
[22] H.A. Ali, K.A.A. El-Shaikh, R.A. Marey, A.Z.S. Boktor, Effect of fertilization with mineral NPK and spraying with Nano NPK on growth, yield and quality of onion, Journal of Sohag Agriscience (JSAS) 6 (2) (2021) 151–169.
[23] R.L. Yadav, N.L. Sen, M.S. Fageria, R.S. Dhaka, Effect of nitrogen and potassium fertilization on quality bulb production of onion, Haryana J. Hortic. Sci. 31 (3/4) (2002) 297, 297.
[24] A. Mukherjee, B. Sikdar, B. Ghosh, A. Banerjee, E. Ghosh, M. Bhattacharya, S.C. Roy, RAPD and ISSR analysis of some economically important species, varieties, and cultivars of the genus Allium (Alliaceae), Turk. J. Bot. 37 (4) (2013) 605–618, https://doi.org/10.3906/bot-1208-18.
[25] J.-H. Son, K.-C. Park, S.-I. Lee, J.-H. Kim, N.-S. Kim, Species relationships among Allium species by ISSR analysis, Horticulture, Environment, and Biotechnology 53 (3) (2012) 256–262, https://doi.org/10.1007/s13580-012-0130-3.
[26] D.M. Salama, M.E. Abd El-Aziz, S.A. Osman, M.S.A. Abd Elwahed, E.A. Shaaban, Foliar spraying of MnO2-NPs and its effect on vegetative growth, production, genomic stability, and chemical quality of the common dry bean, Arab Journal of Basic and Applied Sciences 29 (1) (2022) 26–39, https://doi.org/10.1080/25765299.2022.2032921.
[27] C.R. Azzam, K.A. Zaied, A.H. Abd El-Hadi, N. El-Din, M. Marwa, Genetic relationships among ten sunflower inbred lines based on ISSR and RAPD analyses, Egypt, J. Plant Breed. 23 (4) (2019) 547–563.
[28] D.M. Salama, M.E. Abd El-Aziz, E.A. Shaaban, S.A. Osman, M.S. Abd El-Wahed, The impact of nanofertilizer on agro-morphological criteria, yield, and genomic stability of common bean (*Phaseolus vulgaris* L.), Sci. Rep. 12 (1) (2022) 18552, https://doi.org/10.1038/s41598-022-21834-9.
[29] M.G. Dawood, M.A. Khater, M.E. El-Awadi, Physiological role of osmoregulators proline and glycinebetaine in increasing salinity tolerance of chickpea, Egypt. J. Chem. 64 (12) (2021) 7637–7648, https://doi.org/10.21608/ejchem.2021.85725.4233.
[30] A.A. Deh Sheikh, M. Moradnejad, Mutagenesis in olive (Olea europaea L.) calli caused by sodium azide and detection of mutants using ISSR and RAPD markers, J. Hortic. Sci. Biotechnol. 89 (2) (2014) 153–158, https://doi.org/10.1080/14620316.2014.11513062.
[31] M. Ghosh, A. Jana, S. Sinha, M. Jothiramajayam, A. Nag, A. Chakraborty, A. Mukherjee, A. Mukherjee, Effects of ZnO nanoparticles in plants: cytotoxicity, genotoxicity, deregulation of antioxidant defenses, and cell-cycle arrest, Mutation Research/Genetic Toxicology and Environmental Mutagenesis 807 (2016) 25–32, https://doi.org/10.1016/j.mrgentox.2016.07.006.
[32] D.M. Salama, S.A. Osman, E.A. Shaaban, M.S. Abd Elwahed, M.E. Abd El-Aziz, Effect of foliar application of phosphorus nanoparticles on the performance and sustainable agriculture of sweet corn, Plant Physiol. Biochem. 203 (2023) 108058, https://doi.org/10.1016/j.plaphy.2023.108058.
[33] F.O. Cekic, S. Ekinci, M.S. Inal, D. Ozakca, Silver nanoparticles induced genotoxicity and oxidative stress in tomato plants, Turk. J. Biol. 41 (5) (2017) 700–707, https://doi.org/10.3906/biy-1608-36.
[34] H. Mahmoud, Molecular and cytogenetic assessment of zinc nanoparticles on *Vicia faba* plant cells, Egypt, J. Exp. Biol. 15 (1) (2019) 39–49, https://doi.org/10.5455/egyjebb.20181108065044.
[35] L. Khanna, N.K. Verma, Silica/potassium ferrite nanocomposite: structural, morphological, magnetic, thermal and in vitro cytotoxicity analysis, Mater. Sci. Eng., B 178 (18) (2013) 1230–1239, https://doi.org/10.1016/j.mseb.2013.08.004.
[36] A. Cottenie, M. Verloo, L. Kiekens, G. Velghe, R. Camerlynik, Chemical Analysis of Plant and Soils Lab, Anal. Agroch. Fac. Agric, State University Gent., Belgium, 1982, p. 63.
[37] H.K. Lichtenthaler, A.R. Wellburn, Determinations of Total Carotenoids and Chlorophylls a and B of Leaf Extracts in Different Solvents, Portland Press Limited, 1983.
[38] H. Metzner, H. Rau, H. Senger, Untersuchungen zur synchronisierbarkeit einzelner pigmentmangel-mutanten von Chlorella, Planta 65 (2) (1965) 186–194.
[39] J. Jiang, A. Comar, P. Burger, P. Bancal, M. Weiss, F. Baret, Estimation of leaf traits from reflectance measurements: comparison between methods based on vegetation indices and several versions of the PROSPECT model, Plant Methods 14 (1) (2018) 23.
[40] M. DuBois, K.A. Gilles, J.K. Hamilton, P.A. Rebers, F. Smith, Colorimetric method for determination of sugars and related substances, Anal. Chem. 28 (3) (1956) 350–356, https://doi.org/10.1021/ac60111a017.
[41] T. Hao, Q. Zhu, M. Zeng, J. Shen, X. Shi, X. Liu, F. Zhang, W. de Vries, Quantification of the contribution of nitrogen fertilization and crop harvesting to soil acidification in a wheat-maize double cropping system, Plant Soil (2018), https://doi.org/10.1007/s11104-018-3760-0.
[42] C. Association of Official Analytical, Official Method of Analysis of AOAC International, seventeenth ed., AOAC International Gaithersburg, MD, USA, 2000.
[43] W. Brand-Williams, M.E. Cuvelier, C. Berset, Use of a free radical method to evaluate antioxidant activity, LWT - Food Sci. Technol. (Lebensmittel-Wissenschaft -Technol.) 28 (1) (1995) 25–30, https://doi.org/10.1016/S0023-6438(95)80008-5.

[44] D.H. Diaz, G.C. Martin, Peach seed dormancy in relation to endogenous inhibitors and applied growth Substances1, J. Am. Soc. Hortic. Sci. 97 (5) (1972) 651–654, https://doi.org/10.21273/JASHS.97.5.651.
[45] C.-C. Chang, M.-H. Yang, H.-M. Wen, J.-C. Chern, Estimation of total flavonoid content in propolis by two complementary colorimetric methods, J. Food Drug Anal. 10 (3) (2002) 178–182.
[46] E. Glickmann, Y. Dessaux, A critical examination of the specificity of the salkowski reagent for indolic compounds produced by phytopathogenic bacteria, Appl. Environ. Microbiol. 61 (2) (1995) 793–796, https://doi.org/10.1128/aem.61.2.793-796.1995.
[47] S. Gallik, Determination of the anthocyanin concentration in table wines and fruit juices using visible light spectrophotometry, Cell Biol. 2 (2012) 1–12.
[48] S.S. Nielsen, Food Analysis, Springer, 2010.
[49] C.R. Azzam, Z.M. Abd El-Naby, S.S. Abd El-Rahman, S.A. Omar, E.F. Ali, A. Majrashi, M.M. Rady, Association of saponin concentration, molecular markers, and biochemical factors with enhancing resistance to alfalfa seedling damping-off, Saudi J. Biol. Sci. 29 (4) (2022) 2148–2162, https://doi.org/10.1016/j.sjbs.2021.11.046.
[50] G.W. Snedecor, W.G. Cochran, Statistical Methods, 8thEdn, Iowa State Univ. Press Iowa, Ames, 1989.
[51] A.M.J. Amin, G. Al-Abbasi, H.J.A.M. Alkurdi, Effect of foliar spray with nano-optimus plus and potassium chelated with amino acids in some growth characters of citrus aurantifolia l. Saplings, Plant Archives (09725210) 20 (1) (2020) 897–900.
[52] W.S. Dhillon, A.S. Bindra, B.S. Brar, Response of grapes to potassium fertilization in relation to fruit yield, qualty and petiole nutrient status, J. Indian Soc. Soil Sci. (1) (1999) 47.
[53] D.M. Oosterhuis, D.A. Loka, E.M. Kawakami, W.T. Pettigrew, Chapter three - the physiology of potassium in crop production, in: D.L. Sparks (Ed.), Advances in Agronomy, Academic Press2014, pp. 203-233.
[54] P.K. Hepler, L. Vidali, A.Y. Cheung, Polarized cell growth in higher plants, Annu. Rev. Cell Dev. Biol. 17 (1) (2001) 159–187, https://doi.org/10.1146/annurev.cellbio.17.1.159.
[55] M. Hasanuzzaman, M.H.M.B. Bhuyan, K. Nahar, M.S. Hossain, J.A. Mahmud, M.S. Hossen, A.A.C. Masud Moumita, M. Fujita, Potassium: a vital regulator of plant responses and tolerance to abiotic stresses, Agronomy 8 (3) (2018) 31, 10.3390/agronomy8030031.
[56] M.R. Naderi, A. Abedi, Application of nanotechnology in agriculture and refinement of environmental pollutants, J Nanotechnol 11 (1) (2012) 18–26.
[57] L.V. Subbaiah, T.N.V.K.V. Prasad, T.G. Krishna, P. Sudhakar, B.R. Reddy, T. Pradeep, Novel effects of nanoparticulate delivery of zinc on growth, productivity, and zinc biofortification in maize (Zea mays L.), J. Agric. Food Chem. 64 (19) (2016) 3778–3788, https://doi.org/10.1021/acs.jafc.6b00838.
[58] H. Banerjee, K. Ray, S.K. Dutta, K. Majumdar, T. Satyanarayana, J. Timsina, Optimizing potassium application for hybrid rice (Oryza sativa L.) in coastal saline soils of West Bengal, India, Agronomy 8 (12) (2018) 292, https://doi.org/10.3390/agronomy8120292.
[59] R.A. El-Mergawi, M.S.A. Abdel-Wahed, Diversity in salicylic acid effects on growth criteria and different indole acetic acid forms among faba bean and maize, Egypt. J. Agron. 26 (2004) 49–61.
[60] J. Yang, W. Cao, Y. Rui, Interactions between nanoparticles and plants: phytotoxicity and defense mechanisms, J. Plant Interact. 12 (1) (2017) 158–169, https://doi.org/10.1080/17429145.2017.1310944.
[61] I. El-Metwally, M. Doaa, A.E.-A.M. Abo-Basha, M. Abd El-Aziz, Response of peanut plants to different foliar applications of nano-iron, manganese and zinc under sandy soil conditions, Middle East Journal of Applied Sciences 8 (2) (2018) 474–482.
[62] C.M. Rico, S.C. Lee, R. Rubenecia, A. Mukherjee, J. Hong, J.R. Peralta-Videa, J.L. Gardea-Torresdey, Cerium oxide nanoparticles impact yield and modify nutritional parameters in wheat (*Triticum aestivum* L.), J. Agr. Food Chem. 62 (40) (2014) 9669–9675, https://doi.org/10.1021/jf503526r.
[63] V. Baskar, S. Nayeem, S.P. Kuppuraj, T. Muthu, S. Ramalingam, Assessment of the effects of metal oxide nanoparticles on the growth, physiology and metabolic responses in in vitro grown eggplant (Solanum melongena), 3 Biotech 8 (8) (2018) 362, https://doi.org/10.1007/s13205-018-1386-9.
[64] H.R.L. Benzon, M.R.U. Rubenecia, V.U. Ultra Jr., S.C. Lee, Nano-fertilizer affects the growth, development, and chemical properties of rice, International Journal of Agronomy and Agricultural Research 7 (1) (2015) 105–117.
[65] H. Zafar, A. Ali, J.S. Ali, I.U. Haq, M. Zia, Effect of ZnO nanoparticles on Brassica nigra seedlings and stem explants: growth dynamics and antioxidative response, Front. Plant Sci. 7 (2016) 535, https://doi.org/10.3389/fpls.2016.00535.
[66] L. Zhao, J.R. Peralta-Videa, C.M. Rico, J.A. Hernandez-Viezcas, Y. Sun, G. Niu, A. Servin, J.E. Nunez, M. Duarte-Gardea, J.L. Gardea-Torresdey, CeO2 and ZnO nanoparticles change the nutritional qualities of cucumber (cucumis sativus), J. Agric. Food Chem. 62 (13) (2014) 2752–2759, https://doi.org/10.1021/jf405476u.
[67] M. Thiruvengadam, S. Gurunathan, I.-M. Chung, Physiological, metabolic, and transcriptional effects of biologically-synthesized silver nanoparticles in turnip (Brassica rapa ssp. rapa L.), Protoplasma 252 (4) (2015) 1031–1046, https://doi.org/10.1007/s00709-014-0738-5.
[68] A.J.J. Al-Fahdawi, M.M. Allawi, Impact of biofertilizers and nano potassium on growth and yield of eggplant (Solanum melongena L.), Plant Archives 19 (2) (2019) 1809–1815.
[69] M.O. Jimoh, A.J. Afolayan, Heavy metal uptake and growth characteristics of Amaranthus caudatus L. under five different soils in a controlled environment, Not. Bot. Horti Agrobot. Cluj-Napoca 48 (1) (2020) 417–425.
[70] S. Davarpanah, A. Tehranifar, G. Davarynejad, J. Abadía, R. Khorasani, Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. *Ardestani*) fruit yield and quality, Sci. Hortic. 210 (2016) 57–64.
[71] M. Norozi, B. ValizadehKaji, R. Karimi, M. Nikoogoftar Sedghi, Effects of foliar application of potassium and zinc on pistachio (Pistacia vera L.) fruit yield, Int. J. Hortic. Sci. Technol. 6 (1) (2019) 113–123.
[72] Y.-L. Han, H.-X. Song, Q. Liao, Y. Yu, S.-F. Jian, J.E. Lepo, Q. Liu, X.-M. Rong, C. Tian, J. Zeng, C.-Y. Guan, A.M. Ismail, Z.-H. Zhang, Nitrogen use efficiency is mediated by vacuolar nitrate sequestration capacity in roots of Brassica napus, Plant Physiology 170 (3) (2016) 1684–1698, https://doi.org/10.1104/pp.15.01377.
[73] A.A. Helaly, A.E. Ashmawi, A.A. Mohammed, M.T. El- Abd, A.S. Nofal, Effect of soil application of nano NPK fertilizers on growth, productivity and quality of Lettuce (Lactuca sativa), Al-Azhar Journal of Agricultural Research 46 (1) (2021) 91–100, https://doi.org/10.21608/ajar.2021.218559.
[74] S. Ali, A. Mehmood, N. Khan, Uptake, translocation, and consequences of nanomaterials on plant growth and stress adaptation, J. Nanomater. 2021 (2021) 6677616, https://doi.org/10.1155/2021/6677616.
[75] O. Rubilar, M. Rai, G. Tortella, M.C. Diez, A.B. Seabra, N. Durán, Biogenic nanoparticles: copper, copper oxides, copper sulphides, complex copper nanostructures and their applications, Biotechnol. Lett. 35 (9) (2013) 1365–1375, https://doi.org/10.1007/s10529-013-1239-x.
[76] A. Rasheed, H. Li, M.M. Tahir, A. Mahmood, M. Nawaz, A.N. Shah, M.T. Aslam, S. Negm, M. Moustafa, M.U. Hassan, Z. Wu, The role of nanoparticles in plant biochemical, physiological, and molecular responses under drought stress: a review, Front. Plant Sci. 13 (2022).
[77] M. Kesralikar, S. Mokate, B.A. Golakiya, D.N. Vakharia, Genetic diversity analysis among onion genotypes through RAPD, SSR and ISSR markers, International Journal of Current Microbiology and Applied Sciences 6 (6) (2017) 1467–1474.
[78] G.S. Sudha, P. Ramesh, A.C. Sekhar, T.S. Krishna, P.V. Bramhachari, K. Riazunnisa, Genetic diversity analysis of selected Onion (Allium cepa L.) germplasm using specific RAPD and ISSR polymorphism markers, Biocatal. Agric. Biotechnol. 17 (2019) 110–118, https://doi.org/10.1016/j.bcab.2018.11.007.
[79] A. Brahimi, S. Landschoot, B. Bekaert, L. Hajji, H. Hajjaj, K. Audenaert, G. Haesaert, H. Mazouz, Exploring the genetic and phenotypic diversity within and between onion (Allium cepa L.) ecotypes in Morocco, J. Genet. Eng. Biotechnol. 20 (1) (2022) 96, https://doi.org/10.1186/s43141-022-00381-w.