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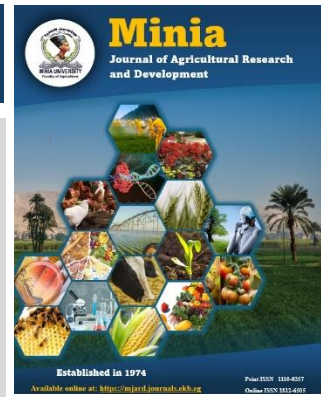

Impact of nano and/or normal fertilizers on quality of some potato cultivars planted under the Middle Egypt growing conditions

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ABSTRACT

Using nano fertilizers in agriculture is very crucial for good production and quality of the products of all field and horticultural crops e.g., potato. In this research we studied the effect of NPK, zinc and boron in the nano and/or normal forms on growth and yield quality of three cooking and processing potato cultivars (Burren, Cara, and Lady Rosetta) under the Middle Egypt (Minia) growing conditions in two successive winter seasons of 2023 and 2024. Results revealed that there were significant differences among the three used cultivars and mixes of nano and/or normal forms of macro and micro elements showed several effects of potato plants growth and tubers quality. When combinations of different fertilizers and mixes were used the potato qualities e.g., marketable and unmarketable yield, and chlorophylls, starch, NPK, zinc and boron contents were in desirable content. The best mix was the combination of 75 % of the recommended normal-NPK dose + Nano-NPK (foliar application) + Nano-micronutrients (foliar Zn and B) which gave all high values of these desirable characteristics. This mix could be recommended to potato farmers of the Middle Egypt and similar growing conditions to increase their income from potato plantation and reduce production costs.

Keywords: Potato, cultivars, Nano fertilizers, NPK, Zinc, Boron, growth, product quality

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the most consumed tuber crop worldwide and is one of the Solanaceae family. One of the most essential foods in many countries is potatoes. Improved tuber yield with good qualities allows the selection of appropriate varieties and more sensible cultivation methods (Reddy *et al.*, 2018; Singh *et al.*, 2018 and Devaux *et al.*, 2021). Since production in developing countries has increased over the past 20 years and is currently higher than in the industrialized world, it is evident how important potatoes are as a staple food crop to meet the demands of expanding

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human populations. It has evolved to thrive in a range of environments, and with several genetic resources available, there is a lot of potential to further exploit its innate biodiversity. It is a nutrient-dense vegetable that contains 15–29% dry matter, 10–25% starch, 1% protein, and 1% mineral salts (Manea *et al.*, 2019). A good variety offers a high yield of high quality, and the genetic component of variety influences potato yields; different variants have varied orthomorphic and genetic attributes. In addition to the quantity and quality of their yield, different potato varieties also differ in how they develop and mature (Hassan, 2003; Al-Taey *et al.*, 2019; Al-Bayati *et al.*, 2023).

Elwan *et al.* (2018) stated that potato is one of Egypt's most important vegetable crops for both export and local home consumption. With 439,328 fed. acres under cultivation, Egypt produced about 5 million tons in 2016 (an average of 11.5 tons per fed.). About 135,000 tons of tuber seeds were imported from European countries in 2016 to be used in Egypt's summer plantings. The seed tubers cost about 62.1 million pounds a year. Baddour and Masoud (2022) concluded from their research that the type and range of fertilizers used can significantly affect the potato crop's yield and tuber quality.

As a result, the cost of creating fertilizer using nanotechnology is becoming comparable enough to encourage wider involvement in the worldwide agriculture industry (Yadav *et al.*, 2023). The promise of nanofertilizers (NFs), sometimes known as smart fertilizers, to boost agricultural yields while lessening their negative effects on the environment has drawn more attention in recent years. To increase agricultural output, nanomaterials are added to conventional fertilizers. Nanoscale particles, often smaller than 100 nanometers, make NFs, a type of fertilizer. They frequently consist of organic compounds like humic acid or chitosan, or metal or metal oxide nanoparticles like iron or zinc oxide. By supplying nutrients effectively and efficiently to the plant, these particles are meant to enhance plant absorption and utilization (Dimkpa and Bindraban, 2017 and Yadav *et al.*, 2023). The advantages of commercializing NFs: reduced production cost, improved crop yield, increased resilience, improved nutrients uptake. improved agricultural sustainability, improved product quality, reduced environmental impact, reduced nutrients loss, improved water use efficiency (Sati *et al.*, 2017; Yadav *et al.*, 2023; Alobaidi and Ibraheem, 2024). Therefore, we aimed in this research to study the impact of nano and/or normal NPK and some micro elements (zinc and boron) on potato tubers production qualities of three potato cultivars grown under the Middle Egypt growing conditions.

MATERIALS AND METHODS

In two successive growing winter seasons of 2023 and 2024 and at a private farm in Manqateen village, Samalout, Minia Governorate, Egypt, field experiments were conducted to investigate the impact of NPK fertilizers (either in normal or nano-forms), and Zn and B (either in chelated or nano-form) on tubers qualities of three potato cultivars namely, Burren (cooking cultivar), Cara (cooking and processing cultivar) and Lady Rosetta (processing cultivar).

Plant materials

Seed-tubers of the three cultivars were obtained from a private farm producing potato seeds. Twenty days before cultivation in the field, green germination was conducted on these potato seed-tubers. The tubers were prepared and treated with fungicide (Mancozeb 80%) and were sown in prepared soil on 15th September in both seasons.

Layout of the experiments

The experiments were arranged in a complete randomized block design (CRBD) with three replicates as split plot design. The treatments included three potato cultivars (in main plots) and six fertilization treatments (in sub plots). So, the total number of the experimental units was 54 (3 cultivars X 6 fertilization treatments X 3 replicates). The experimental unit (plot) was 3.5 x 3.0 m, equal 10.5 m^2 (1/400 feddan) and contained 4 ridges, 20 cm apart to count 72 plants (4 ridges X 18 plants). The physical and chemical properties of the used soil are listed in table 1. During preparing the soil for potato cultivation in both seasons, chicken manure at a rate of 12 m^3, 500 kg Ca-super phosphate (15.5% P_2O_5), 15 kg potassium sulfate (48% K_2O), and 10 kg magnesium sulfate (16% MgO) and 50 kg agricultural sulfur/feddan were added. This pre-planting preparation of the soil matched the instructions of the Egyptian Ministry of Agriculture and Soil Reclamation.

Thirty-five days after sowing potato seed-tubers of the three cultivars and after complete emergence, the first dose of nitrogen was added as urea (46% N). Three weeks later, the second dose was added as ammonium nitrate (33.5% N). When potato plants reached 55 days, potassium nitrate was applied according to the recommendations of the Egyptian Ministry of Agriculture and Soil Reclamation.

Treatments

Potato cultivars: three potato cultivars, namely, Burren, Cara and Lady Rosetta.

Fertilization treatments:

1. 100% of the recommended normal-NPK (100 kg/fed.).
2. 50% of recommended normal-NPK (50 kg/fed.).
3. 75% of the recommended normal-NPK (100 kg/fed.) + Nitrolef (foliar application) + micronutrients (Zn and B).
4. 50% of the recommended normal-NPK + Nitrolef + micronutrients (Zn and B).
5. 75% recommended normal-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano-micronutrients (Zn and B).
6. 50% of the recommended normal-NPK + Nano-NPK (foliar application) + Nano-micronutrients (Zn and B).

The NPK-fertilization treatments started 70 days after sowing the potato tuber-seeds. Foliar application of all normal NPK (urea, 46% N and ammonium nitrate, 33.5% N), Nitrolef (20:20:20 NPK) and Nano-NPK (12:6:8 NPK) were applied twice (70 and 85 days after sowing the potato tuber-seeds). Similarly, microelements; Zn and B were sprayed two times, Granora cleated zinc (13% ZnO) and boron (11.5% BO_3) and Nano forms of these microelements (6% Zn) and (14% BO_3), respectively were foliar sprayed on plants two days after NPK application in both seasons. All nano fertilizers were purchased from Faculty of Agriculture, Cairo University, Egypt, which locates in El Dokki districts, Giza Governorate, Egypt.

Recorded data of chemical analysis

Potato tubers quality

Some tubers' qualitative characteristics were measured as follows:

1. Tuber vertical and horizontal diameters (length and width) in cm.
2. Marketable tubers percentage (more than 4.5 cm in diameter).
3. Unmarketable tuber percentage (less than 4.5 cm in diameter).

Chemical analysis (pigments and elements determination)

Leaves' samples were collected after 70 days from potato seed-tubers sowing (25th November).

1. **Chlorophyll a, b and carotenoids content determination:** The content of chlorophyll a, b, and carotenoids in potato fresh leaves' samples was measured using the **Moran (1982)** method as mg/g fresh leaves.
2. **Macro- and micro-elements (%)**

- To determine N, P and K concentrations in potato leaves and tubers, 0.4 g crude dried kept powder from each sample was wet digested with a mixture of concentrated sulfuric (H_2SO_4) and perchloric ($HClPO_4$) acids, then heated until it became clear solution. This solution was quantitively transferred into 100 ml measuring flask and kept for determinations (Gotteni, 1982). The modified Micro-kjeldahl apparatus was employed for total N-determination as described by Jones *et al.* (1991).
- Total phosphorus was determined spectrophotometrically by Milten Roy spectronic 120 at wavelength 725 nm using stannous chloride reduced molybdosulphoric blue color method in sulfuric system as described by Peters *et al.* (2003).
- Total potassium was estimated Flame photometrically using Jenway Flame photometer, Model corning 400 according to the modified method of Peters *et al.* (2003).
- Boron was determined by Carmine method described by Sarkar *et al.* (2014).

- Zinc was determined as follow: dried and finely ground plant tissues were subjected to wet digestion using a mixture of concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 4:1 ratio. Approximately 0.5 g of the plant material was digested on a hot plate at 120–150°C until a clear solution was obtained. After cooling, the digested samples were filtered and brought to a known volume with deionized water. The concentrations of zinc (Zn) were measured using Atomic Absorption Spectrophotometry (AAS), following the procedures described by Alloway (2008).

3. **Starch content** (mg/g): Starch was determined by the method of Antheron reagent as described by Thymanavan and Sadasivam, (1984). Tuber samples were treated with 80 % ethanol to remove starchs and then starch was extracted with perchloric acid. In hot acidic medium, starch is hydrolyzed to glucose and hydrated to hydroxymethyl furfural. This compound forms a green-colored product with antherone. The intensity of green to dark green colour was estimated photometrically at wavelength of 630 nm. Glucose content was calculated in the sample using standard curve and the value was multiplied by a factor of 0.9 to arrive the starch content.

Statistical analysis

All obtained data were subjected to the analysis of variance and means were compared using the LSD test at 5% using the MSTAT–C software Ver. 4 according to Gomez and Gomez (1986).

RESULTS AND DISCUSSION

Tuber size (length and width, cm)

Tables 3 and 4 list the effects of fertilization forms (NPK, Zn, and B) on the tuber length and width (cm) of three potato cultivars (Lady Rosetta, Cara, and Burren) at harvest during both growth seasons. Table (9) makes it clear that the three cultivars (Lady Rosetta, Cara, and Burren) differed significantly in terms of tuber length (cm) during both harvest seasons. In both seasons, Lady Rosetta recorded the shortest tubers (6.03 and 7.70 cm), while the Burren cultivar recorded the longest (7.73 and 10.38 cm). Concurrently, intermediate results (6.48 and 8.92 cm) were produced by the Cara cultivar. The Cara cultivar did not significantly outperform. Regarding the impact of potato cultivars on tuber width, table 4 found that, with the exception of Lady Rosetta and Burren in the second season alone, tuber width (cm) rose negligibly. Between the two cultivars, the Cara cultivar accumulated intermediate order. Cara cultivar (5.77 cm), Burren cultivar (7.75 cm), and Lady Rosetta cultivar (5.40 cm) were in descending order of tube width in the first season, while Burren cultivar (7.95 cm) was followed by Cara cultivar (7.30 cm) and Lady Rosetta cultivar (6.20 cm) in the second season. Tuber length (cm) increased in both seasons when potato plants were fertilized with any of the available fertilization types. This improvement was not substantial, though. The treatment of [half dose of recommended traditional-NPK (50 kg/fed.) + Nitrolef (foliar application) + Chelated (Zn and B)] produced the longest tubers (7.09 and 9.59 cm) in both seasons. The first season was treated with [half dose of recommended traditional-NPK (50 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B)], and the second season was treated with [full dose of recommended traditional-NPK (100 kg/fed.)].

All of the fertilization types that were used collected the same amount of significance in both seasons with regard to tuber width. However, the widest tuber was observed after the first season's treatment of [50% of the dose of recommended traditional-NPK (50 kg/fed.) + Nano (foliar application) + Nano (Zn and B)], followed by the second season's treatment of [full dose of recommended traditional-NPK (100 kg/fed.)] and the first season's treatment of [half dose of recommended traditional-NPK (50 kg/fed.) + Nitrolef (foliar application) + Chelated (Zn and B)]. Our results are consistent with those of numerous authors, including Nizamuddin *et al.* (2003), Abd El-Azeim *et al.* (2019), Al-Abdali *et al.* (2021), Kumar *et al.* (2022), Abdulkadhum *et al.* (2023), and Al-Sultan *et al.* (2023), who highlighted the beneficial effects of NPK fertilization (either in traditional or nano form) on the tuber size of potato plants. Additionally, as noted by Rahman *et al.* (2018), Al-Juthery *et al.* (2019), Mahmoud *et al.* (2020), Al-Sharifi and Al-Zubaidi (2023), Rashwan *et al.* (2023), Alobaidi and Ibraheem (2024), and Salama and Haggag (2024), Zn and B fertilization (either in Chelated or Nano form) supported the increase in tuber size. Tuber size (length and width) in the two seasons was significantly impacted by the interplay of the three potato cultivars and fertilization types. The Burren cultivar treated with [50% normal-NPK + Nano-NPK (foliar application) + Nano (Zn and B)] in the first season typically produced the longest tuber (8.09 cm), whereas the cultivar treated with [50% normal-NPK + Nitrolef (foliar application) + Chelated (Zn and B)] in the second season produced the longest tuber (12.05 cm). Tables 9 and 10 demonstrate that the Cara cultivar treated with [50% normal-NPK + Nitrolef (foliar application) + Chelated (Zn and B)] in the first season produced the widest tuber (6.0 cm), while the cultivar treated with [75% normal-NPK + Nano-NPK (foliar application) + Nano (Zn and B)] in the second season produced the widest tuber (8.64 cm).

Marketable and unmarketable tuber yield (%)

Tables 5 and 6 list the effects of fertilization forms (NPK, Zn, and B) on the marketable and unmarketable tuber yield (%) of three potato cultivars (Lady Rosetta, Cara, and Burren) at harvest during both growing seasons. Marketable tuber yield (greater than 4.5 cm) varied significantly depending on the potato cultivars (Lady Rosetta, Cara, and Burren) during the first season alone, as shown by the statistics in Table 13. In both seasons, Lady Rosetta had the lowest significant marketable tuber yield (76.363 and 85.138%), while the Burren cultivar had the highest marketable tuber yield (86.903 and 88.500%). In both seasons, however, the Cara cultivar yielded intermediate levels (82.277 and 86.852%).

In the first season, potato cultivars had a significant impact on unmarketable output (less than 4.5 cm) (Table 6). In both seasons, Lady Rosetta achieved the greatest significant values (23.632 and 14.862%), whereas the Burren cultivar recorded the lowest unmarketable tuber yield (13.097 and 11.500%) due to the tendency of unmarketable tubers to offset the yield of marketable tubers. Additionally, in both seasons, the Cara cultivar yielded intermediate results (17.722 and 13.175%). Marketable and unmarketable tuber yield (%) in both seasons were unaffected by fertilization types, according to data from the preceding Tables. However, the most marketable tubers (favored by customers) were obtained under the treatment of [75% of the prescribed traditional-NPK (100 kg/fed.)], yielding 86.811 and 92.253% in both seasons. However, the treatment of [full dose of recommended traditional-NPK (100 kg/fed.) + Nitrolef (foliar application) + Chelated (Zn and B)] in the first season and [half dose of recommended traditional-NPK (50 kg/fed.) + Nitrolef (foliar application) + Chelated (Zn and B)] in the second season produced the highest unmarketable tubers (22.430 and 16.333%), which is not preferred.

Nizamuddin *et al.* (2003), Al-Bayati *et al.* (2018), Singh *et al.* (2018), Al-Taey *et al.* (2019), Kumar *et al.* (2021), Abdulkadhum *et al.* (2023), Al-Bayati *et al.* (2023), and Al-Sultan *et al.* (2023) all highlighted the beneficial impact of NPK fertilization (either in traditional or nano form) on marketable tuber yield. Additionally, the increase in marketable tuber production was promoted by Zn and B fertilization (either in Chelated or Nano form) (Rahman *et al.*, 2018; Al-Juthery *et al.*, 2019; Al-Zebari *et al.*, 2021; Al-Selwey *et al.*, 2023; Dhiman *et al.*, 2024). For both marketable and unmarketable tuber yield (%) in the first season, there was a substantial interaction between the three potato cultivars and fertilization types. The Burren cultivar treated with [half dose of recommended traditional-

NPK (50 kg/fed.)] had the highest marketable tuber yield (less unmarketable tuber) in the first season, gaining 93.330% marketable tubers and 6.669% unmarketable tubers.

Effect of these different fertilizers on some chemical compositions

Photosynthetic pigments (mg/g FW)

Tables 7, 8, and 9 show the effects of fertilization with NPK, Zn, and B on the levels of chlorophyll a, b and carotenoids (mg/g FW) and, and three potato cultivars at 70 days after planting throughout both growing seasons. Tables 7, 8, and 9 make it clear that, at 70 days after planting, there were notable variations in the levels of carotenoids and chlorophyll "a" among the three cultivars (Lady Rosetta, Cara, and Burren), but not in chlorophyll b. In the first season, Burren reported the lowest pigment content (1.054, 1.446, and 1.291 mg/g) for carotenoids, chlorophyll a, and chlorophyll b, respectively, whereas the Lady Rosetta cultivar typically recorded the greenest leaves (1.467, 1.538, and 1.438 mg/g). The Cara cultivar simultaneously generated moderate levels of chlorophyll a, b and carotenoids (1.266, 1.417, and 1.509 mg/g). The same patterns were seen in the second season.

Treating potato plants with the utilized fertilization forms in both seasons resulted in a considerable improvement in the levels of carotenoids, chlorophyll a, and chlorophyll b (mg/g FW). Both seasons were treated with 75% of the prescribed dose of traditional-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B)], with the exception of the first season, which provided results from the identical treatment with no discernible variations. Chlorophyll a, b, and carotenoids levels in the superior treatment were 1.451, 1.659, and 1.787 mg/g in the first season and 1.423, 1.598, and 1.587 mg/g in the second. However, in the majority of cases, the administration of [half dose of required traditional-NPK (50 kg/fed.)] produced the lowest pigment concentration. or [50 kg/fed.] half dose of the suggested traditional-NPK + foliar Nitrolef + Chelated (Zn and B)]. Our results are consistent with numerous authors, including Janmohammadi *et al.* (2016), Al-Taey *et al.* (2019), Al-Zebari *et al.* (2021), Al-Bayati *et al.* (2023), Al-Sultan *et al.* (2023), and Mahmood *et al.* (2025a), who highlighted the beneficial effects of NPK fertilization (either in traditional or nano form) on potato leaf pigments. Similarly, as observed by Mahmoud *et al.* (2020), Marzouk *et al.* (2022), Al-Selwey *et al.* (2023), Al-Sharifi and Al-Zubaidi (2023), and Rashwan *et al.* (2023), Zn and B fertilization (either in Chelated or Nano form) encouraged the enhancement of photosynthetic pigments. For the pigment content (carotenoids, chlorophyll a, and chlorophyll b) in the two seasons, the combined influence of the three potato cultivars and fertilization types was substantial. In every instance, the cultivar of Lady Rosetta fertilized with [75% normal-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B)] produced the highest values for chlorophyll a, chlorophyll b, and carotenoids (1.763, 1.925, and 1.816 mg/g in the first season and 1.570, 1.652, and 1.832 mg/g in the second season, respectively).

Macro elements (%)

Tables (10, 11, and 12) detailed the effects of fertilization forms (NPK, Zn, and B) on the percentages of nitrogen, phosphorus, and potassium in the leaves of three potato cultivars (Lady Rosetta, Cara, and Burren) at 70 days from planting to the second growth season. According to the data in these tables the three cultivars differed significantly in their percentages of nitrogen and potassium, but not in their percentages of phosphorus. Lady Rosetta and the Cara cultivar were identical in terms of nitrogen (%), however both were noticeably higher than the Burren variety. Additionally, the three cultivars were statistically impacted by potassium (%) and ranked in descending order: Lady Rosetta > Cara > Burren. When it came to nitrogen, phosphorus, and potassium percentages, the Lady Rosetta cultivar consistently had the highest values (1.624, 0.371, and 3.529 percent), whereas Burren had the lowest values (1.506, 0.358, and

3.420 percent). Concurrently, the Cara cultivar yielded the intermediate values (1.582, 0.365, and 3.478%).

Treating potato plants with the utilized fertilization forms resulted in a significant increase in the percentages of nitrogen, phosphorous, and potassium. The best fertilizers for raising NPK% were nano-fertilizers. Nitrogen, phosphorus, and potassium levels were highest (1.819, 0.408, and 3.870%) when 50% of the suggested traditional-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B) was applied. However, the half dose of the suggested traditional-NPK (50 kg/fed.) resulted in the lowest nitrogen, phosphorus, and potassium percentages (1.299, 0.318, and 3.064%, respectively). Our results are consistent with those of other writers, including Abd El-Azeim *et al.* (2019), Elshamy *et al.* (2019), and Mahmood *et al.* (2025b), who have discussed the increasing effect of NPK fertilization (Nano form) on NPK%. Likewise, Zn and B fertilization (Nano form) boosted the NPK% as pointed out by Al-Juthery *et al.* (2019), Marzouk *et al.* (2022), Manikanta *et al.* (2023), Rashwan *et al.* (2023) and Salama and Haggag (2024).

For nitrogen, phosphorus, and potassium (%), the combined effect of the three potato cultivars and fertilization types was noteworthy. The Lady Rosetta cultivar fertilized with [full dose of approved traditional-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B)] yielded the highest percentages in each case (1.840, 0.413, and 3.920, respectively). Conversely, the Burren cultivar fertilized with [half dose of prescribed traditional-NPK (50 kg/fed.)] showed the lowest percentages in the combined treatment.

Zinc and boron (mg/kg)

Tables 13 and 14 list the effects of fertilization forms (NPK, Zn, and B) on zinc and boron (mg/kg) in the leaves of three potato cultivars at 70 days from planting through the second growth season. In the second season, 70 days after planting, the three examined cultivars had a substantial impact on the zinc and boron content of potato leaves. The cultivars of Lady Rosetta had the highest Zn and B contents (46.161 and 21.971 mg/kg), followed by Cara (44.243 and 20.890 mg/kg) and Burren (42.947 and 20.133 mg/kg). Fertilizing potato plants using used fertilizer forms increased their zinc and boron levels. The maximum concentrations of Zn and B (51.867 and 25.692 mg/kg, respectively) were obtained at 50% of the prescribed traditional-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B) treatment. Conversely, the treatment of [50% of required traditional-NPK dose (50 kg/fed.)] resulted in the lowest Zn and B readings (35.449 and 15.921 mg/kg). Tables 13 and 14 show that the other fertilization treatments received intermediate orders. Our results are consistent with those of numerous writers, including Janmohammadi *et al.* (2016), Kumar *et al.* (2022); Chauhan *et al.* (2023); Alobaidi and Ibraheem (2024). For zinc and boron (mg/kg) in the second season, the combined effect of the three potato cultivars and fertilization types was noteworthy. In every instance, the Lady Rosetta cultivar fertilized with [75% of traditional-NPK dose (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B)] produced the greatest values for zinc and boron (53.150 and 26.487 mg/kg). In comparison, the Burren cultivar treated with [half dose of prescribed traditional-NPK (50 kg/fed.)] had the lowest zinc and boron values (34.093 and 15.190 mg/kg, respectively) from the combined treatment.

Starch content (mg/g)

The impact of fertilizing three potato cultivars (Lady Rosetta, Cara, and Burren) with NPK, Zn, and B on their starch content (mg/g) at 70 days from planting to the second growth season was reported in table 15. It clear that the three cultivars under investigation (Lady Rosetta, Cara, and Burren) have significantly different starch contents (mg/g). Burren had the lowest starch content (16.036 mg/g), whereas Lady Rosetta had the greatest significant starch level (17.143 mg/g). Concurrently, the Cara cultivar yielded an intermediate value of 16.503 mg/g.

The starch content (mg/g) was considerably increased by all fertilization forms used. The best value was obtained with the treatment of [full dose of recommended traditional-NPK (100 kg/fed.) + Nano-NPK (foliar application) + Nano (Zn and B)]. The starch level of this superior treatment increased to 19.284 mg/g. Conversely, the treatment of [half dose of prescribed traditional-NPK (50 kg/fed.)] yielded the lowest starch content, 13.736 (mg/g). Values from the other fertilization treatments were in the middle. Our results are consistent with those of numerous authors, including Janmohammadi *et al.* (2016), Mijweil and Abboud (2018), Abd El-Azeim *et al.* (2019), Elshamy *et al.* (2019), Al-Zebari *et al.* (2021), and others, who highlighted the beneficial effects of NPK fertilization (either in traditional or nano form) on the starch content of potato leaves. Al-Hayani and Sallume (2023), Al-Sultan *et al.* (2023), Chauhan *et al.* (2023), Mousa *et al.* (2024), Mahmood *et al.* (2025b), Baddour and Masoud (2022), and Al-Bayati *et al.* (2023).

Similar findings were made by Al-Juthery *et al.* (2019), Marzouk *et al.* (2022), and Monika *et al.* (2024) about the improvement of potato starch content by zinc and boron fertilization (either in chelated or nano form). For starch content, the three potato cultivars and fertilization types had a substantial combined influence. Lady Rosetta fertilized with [50% of required traditional-NPK (100 kg/fed.) + Nano-NPK (foliar treatment) + Nano (Zn and B)] had the greatest value (19.77 mg/g). Conversely, Burren fertilized with [half dose of prescribed traditional-NPK (50 kg/fed.)] had the lowest value (13.297 mg/g).

NPK fertilization promotes the continuation of vegetative development and probably speeds up photosynthetic rate, increasing tuber weight and quantity. This may help to clarify how the properties of tuber production are improved when NPK is applied to a specific amount. These results may also be caused by improved root growth, which expands the root's absorbing area, and the availability of N, P, and K elements for plants. Because mineral fertilizer salts are soluble and nitrogen is immediately available for plant uptake, chemical fertilization had the highest nitrate content, according to the influence on NO_3 and NO_2 data; in contrast, organic N fertilizers release nutrients gradually. Because of the 100% prescribed dose of NPK, there was a larger increase in plant height and root length, which might have led to the highest incremental gain in tuber production. Plants fed with inorganic fertilizer may grow taller due to increased metabolic activity in crops (Krishnappa, 1995). Since nitrogen is a component of proteins, amino acids, nucleic acids, chlorophyll, and enzymes, it is necessary for photosynthesis and vegetative development (Haverkort *et al.*, 2016). A sufficient supply of nitrogen promotes strong canopy growth, which in turn boosts photosynthetic activity and biomass accumulation. Conversely, excess N inhibits tuber initiation, delays maturation, and reduces tuber dry matter. promotes vegetative growth and decreases yield stability.

Cell division, root growth, and energy metabolism all depend on phosphorus. It is a part of phospholipids, nucleic acids, and ATP (Singh *et al.*, 2018). It promotes uniform tuber initiation and enhances early root development by promoting the transport of carbohydrates from leaves to developing tubers. By accelerating early vegetative growth and root system development, enough P guarantees better nutrition and water absorption, enhances tuber formation and growth by facilitating the transfer of energy during the digestion of carbohydrates (Haverkort *et al.*, 2016). enhances the cooking quality and storage capacity of tubers by increasing their starch and dry matter content. Osmotic regulation, enzyme activation, and the metabolism of carbohydrates all depend on potassium. It helps potatoes resist stress and combat illnesses by maintaining water balance and turgor pressure. K facilitates the transmission of photosynthate from leaves to tubers, which impacts both production and quality. increases the accumulation of carbohydrates, which improves tuber bulking and increases size and weight, decreases reducing sugars and increases starch content, specific gravity, and vitamin C levels—all of which are critical for processing quality (Haverkort *et al.*, 2016); and increases photosynthetic efficiency and leaf turgidity, which promote long-term growth under stress. According to Sangakkara *et al.* (2000), K plays a part in biochemical pathways in plants that enhance photosynthesis, CO_2 absorption, and carbon movements—all of which support the growth of potato plants.

The meristematic development of plants and physiological functions like protein union, compound actuation, starch movement, photosynthesis, and the regulation of gas and water trade in plants are all significantly impacted by potassium. Additionally, during root development, K is necessary for the migration of photoassimilates. It is evident that the levels of N, P, K, and chlorophyll in potato cultivars are increasing. These results could be related to the gene activity of the cultivars being studied. Potassium is a very specific monovalent cation that is associated with metabolic activity. Together with its companion anions, it is the most prevalent cation in the cytoplasm and plays a major role in the osmotic capacity of tissues and cells. It stands out to be incredibly versatile in plants of all sizes. K is crucial for the plant's water interactions in addition to being non-metabolized and easily forming interchangeable weak complexes. Potassium is a crucial osmotically active cation of plant cells that improves root permeability, guard cell controller function, water absorption, and water usage efficiency. Furthermore, because potassium helps the potato leaves synthesize photosynthates, transports them to the tubers, and enhances their conversion into vitamins, protein, and starch, it is vital for tuber bulking and composition. As a result, potassium plays a critical role in the development of quality.

CONCLUSION AND RECOMMENDATIONS

In this research, the impact of fertilization with nitrogen, phosphorus, potassium, zinc, and boron as nano and/or normal forms on growth and production quality of three potato cultivars (Burren, Cara, and Lady Rosetta) was studied. Results revealed that using combination of 75 % of the recommended traditional-NPK dose (100 kg/fed.) + Nano-NPK (foliar application) + Nano-micronutrients (Zn and B)] recorded the highest and best values of all desirable quality characteristics of potato, e.g., marketable yield, and chlorophylls, starch, NPK, Zinc and Boron contents which were in desirable contents in two successive winter seasons of 2023 and 2024. This mix could be recommended to potato farmers of the Middle Egypt region and similar environments all over the world.

Table 1: Physical and chemical analysis of the experimental soil before plantation of the two seasons of 2023 and 2024

Soil character	Values		Soil character	Values	
	2023	2024		2023	2024
Physical properties:			**Soluble nutrients:**		
Sand (%)	24.56	23.85	**Ca^{++} (mg/100 g soil)**	2.42	2.33
Silt (%)	28.23	27.11	**Mg^{++} (mg/100 g soil)**	1.14	1.11
Clay (%)	47.21	49.04	**Na^{+} (mg/100 g soil)**	1.71	1.62
Soil type	Clay	Clay	**K^{+} (mg/100 g soil)**	0.89	0.81
Chemical properties:			**DTPA-Extractable nutrients:**		
pH (1:2.5)	7.91	7.92	**Fe (ppm)**	3.41	3.42
E.C. (dS/m)	1.24	1.26	**Cu (ppm)**	1.29	1.26
Organic Mater	1.35	1.29	**Zn (ppm)**	1.94	1.93
$CaCO_3$	2.12	2.17	**Mn (ppm)**	3.21	3.25

Table 2: Chemical analysis of the used chicken manure in both seasons of 2023 and 2024

Properties	Value	Properties	Value
Organic carbon (%)	21.12	Total N (%)	5.52
Humidity (%)	39.73	K^{+} (ppm)	538
Protein	34.5	Na^{+} (ppm)	93
C/N ratio	3.83	Ca^{++} (ppm)	1635
pH (1:2.5)	6.1	Mg^{++} (ppm)	103

Table (3): Effect of normal and nano fertilizers on tuber length (cm) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
First season (2023)				
1	6.05 CD	6.82 BC	7.62 AB	**6.83 A**
2	6.04 CD	6.76 BC	7.55 AB	**6.78 A**
3	5.70 C	6.87 BC	7.59 AB	**6.72 A**
4	6.11 CD	7.25 AB	7.91 A	**7.09 A**
5	6.20 CD	6.61 BCD	7.61 AB	**6.81 A**
6	6.10 CD	6.76 BC	8.09 A	**6.98 A**
Mean (A)	**6.03 C**	**6.84 B**	**7.73 A**	
L.S.D. (5%)	**A: 0.53**	**B: 0.64**	**AB: 0.94**	
Second season (2024)				
1	7.96 BCD	8.85 BCD	10.31 ABC	**9.04 A**
2	7.27 D	8.47 BCD	10.16 ABC	**8.64 A**
3	7.534 CD	8.56 BCD	9.26 ABCD	**8.45 A**
4	7.71 CD	9.00 BCD	12.05 A	**9.59 A**
5	7.91 BCD	10.26 ABC	9.80 ABCD	**9.32 A**
6	7.82 CD	8.40 BCD	10.70 AB	**8.97 A**
Mean (A)	**7.70 B**	**8.92 AB**	**10.38 A**	
L.S.D. (5%)	**A: 1.83**	**B: 1.30**	**AB: 2.53**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (4): Effect of normal and nano fertilizers on tuber width (cm) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
First season (2023)				
1	5.78 ABC	5.70 ABC	5.61 ABC	**5.70 A**
2	5.49 ABC	5.73 ABC	5.76 ABC	**5.66 A**
3	5.06 C	5.90 AB	5.70 ABC	**5.56 A**
4	5.32 ABC	6.00 A	5.92 AB	**5.75 A**
5	5.52 ABC	5.45 ABC	5.82 AB	**5.60 A**
6	5.21 BC	5.83 AB	5.69 ABC	**5.58 A**
Mean (A)	**5.40 A**	**5.77 A**	**5.75 A**	
L.S.D. (5%)	**A: 0.45**	**B: 0.53**	**AB: 0.65**	
Second season (2024)				
1	6.46 ABC	7.59 ABC	7.84 ABC	**7.30 A**
2	5.90 C	6.39 ABC	7.98 ABC	**6.76 A**
3	6.04 BC	7.24 ABC	7.47 ABC	**6.92 A**
4	6.00 BC	7.00 ABC	8.47 AB	**7.16 A**
5	6.34 ABC	8.64 A	7.60 ABC	**7.52 A**
6	6.48 ABC	6.92 ABC	8.34 ABC	**7.25 A**
Mean (A)	**6.20 B**	**7.30 AB**	**7.95 A**	
L.S.D. (5%)	**A: 1.40**	**B: 1.23**	**AB: 2.29**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (5): Effect of normal and nano fertilizers on marketable tuber yield (%) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	81.020 AB	87.450 AB	91.963 AB	**86.811 A**
2	73.463 AB	87.023 AB	93.330 AB	**84.606 A**
3	71.693 B	82.840 AB	78.177 AB	**77.570 A**
4	72.557 AB	82.650 AB	85.947 AB	**80.384 A**
5	81.307 AB	69.260 AB	83.533 AB	**78.033 A**
6	78.140 AB	84.440 AB	88.470 A	**83.683 A**
Mean (A)	**76.363 B**	**82.277 AB**	**86.903 A**	
L.S.D. (5%)	**A: 8.444**	**B: 12.81**	**AB: 18.09**	
		Second season (2024)		
1	94.443 A	90.650 A	91.667 A	**92.253 A**
2	90.277 A	76.667 A	91.667 A	**86.203 A**
3	84.443 A	89.167 A	88.333 A	**87.314 A**
4	83.333 A	83.333 A	84.333 A	**83.667 A**
5	82.220 A	90.950 A	88.333 A	**87.168 A**
6	76.110 A	90.183 A	86.667 A	**84.320 A**
Mean (A)	**85.138 A**	**86.852 A**	**88.500 A**	
L.S.D. (5%)	**A:26.45**	**B:22.49**	**AB:26.97**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (6): Effect of normal and nano fertilizers on unmarketable tuber yield (%) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024.

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	18.982 ABC	12.550 ABC	8.037 BC	**13.189 A**
2	26.537 ABC	12.976 ABC	6.669 C	**15.394 A**
3	28.307 A	17.160 ABC	21.823 ABC	**22.430 A**
4	27.443 AB	17.349 ABC	14.055 ABC	**19.610 A**
5	18.693 ABC	30.740 A	16.467 ABC	**21.967 A**
6	21.860 ABC	15.560 ABC	11.530 ABC	**16.317 A**
Mean (A)	**23.632 A**	**17.722 AB**	**13.097 B**	
L.S.D. (5%)	**A: 8.444**	**B: 12.81**	**AB: 18.09**	
		Second season (2024)		
1	5.557 A	9.352 A	8.333 A	**7.747 A**
2	9.723 A	23.333 A	8.333 A	**13.797 A**
3	15.557 A	10.833 A	11.667 A	**12.686 A**
4	16.667 A	16.667 A	15.667 A	**16.333 A**
5	17.780 A	9.050 A	11.667 A	**12.832 A**
6	23.890 A	9.817 A	13.333 A	**15.680 A**
Mean (A)	**1.862 A**	**13.175 A**	**11.500 A**	
L.S.D. (5%)	**A: 26.47**	**B: 22.49**	**AB: 26.97**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (7): Effect of normal and nano fertilizers on Chlorophyll "a" (mg/g fresh weight) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
First season (2023)				
1	1.678 A	1.079 F	1.165 D-F	**1.307 A**
2	1.281 C-F	1.141 EF	0.667 G	**1.030 B**
3	1.635 AB	1.602 AB	1.134 EF	**1.457 A**
4	1.146 EF	1.069 F	0.639 G	**0.951 B**
5	1.763 A	1.320 C-E	1.279 C-F	**1.451 A**
6	1.300 C-F	1.385 CD	1.451 BC	**1.379 A**
Mean (A)	1.467 A	1.266 B	1.054 C	
L.S.D. (5%)	**A: 0.16**	**B: 0.22**	**AB: 0.20**	
Second season (2024)				
1	1.310 A-C	1.327 A-C	1.307A-C	**1.310 A**
2	1.212 BC	1.414 AB	0.736 DE	**1.121 B**
3	1.499 AB	1.363 AB	1.242 A-C	**1.368 A**
4	1.000 CD	0.698 DE	0.712 DE	**0.803 C**
5	1.570 A	1.358 AB	1.341 A-C	**1.423 A**
6	1.311 A-C	1.450 AB	0.596 E	**1.119 B**
Mean (A)	1.315 A	1.268 A	0.989 B	
L.S.D. (5%)	**A: 0.23**	**B: 0.15**	**AB: 0.30**	

Where:
1: 100% of normal-NPK (100 kg/fed.).
2: 50% of normal-NPK (50 kg/fed.).
3: 75% of normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% of normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% of normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (8): Effect of normal and nano fertilizers on Chlorophyll "b" (mg/g fresh weight) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
First season (2023)				
1	1.678 A-C	1.395C-G	1.511 B-E	**1.534 A**
2	1.092 G	1.434C-G	1.140 FG	**1.222 B**
3	1.794 AB	1.411C-G	1.588 A-D	**1.598 A**
4	1.206 E-G	1.313D-G	1.285 D-G	**1.268 B**
5	1.925 A	1.459B-F	1.593 A-D	**1.659 A**
6	1.509 B-E	1.489 B-E	1.561 B-D	**1.520 A**
Mean (A)	**1.538 A**	**1.417 A**	**1.446 A**	
L.S.D. (5%)	**A: 0.22**	**B: 0.24**	**AB: 0.30**	
Second season (2024)				
1	1.368A-E	1.444A-E	1.443A-E	**1.418 B**
2	1.136 D-F	1.078 EF	0.854 F	**1.023 C**
3	1.523 A-D	1.470 A-E	1.594 AB	**1.529 AB**
4	1.185 C-F	1.131 D-F	0.831 F	**1.049 C**
5	1.652 A	1.543 A-C	1.600 AB	**1.598 A**
6	1.219 B-F	1.193 C-F	0.883 F	**1.098 C**
Mean (A)	**1.347 A**	**1.310 A**	**1.201 A**	
L.S.D. (5%)	**A: 0.32**	**B: 0.14**	**AB: 0.35**	

Where:
1: 100% of normal-NPK (100 kg/fed.).
2: 50% of normal-NPK (50 kg/fed.).
3: 75% of normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% of normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% of normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (9): Effect of normal and nano fertilizers on Carotenoids (mg/g fresh weight) at harvest of three potato cultivars grown in two successive winter seasons of 2023 and 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	1.219 FG	1.403C-G	1.366C-G	**1.329 B**
2	1.193 FG	1.244 E-G	1.690 H	**1.042 C**
3	1.773 A	1.545A-E	1.627 A-D	**1.648 A**
4	1.305 E-G	1.455B-F	1.114 G	**1.291 B**
5	1.816 A	1.758 AB	1.787 A	**1.787 A**
6	1.325 D-G	1.649 A-C	1.163 FG	**1.379 B**
Mean (A)	**1.438 A**	**1.509 A**	**1.291 A**	
L.S.D. (5%)	**A: 0.27**	**B: 0.17**	**AB: 0.28**	
		Second season (2024)		
1	1.765 AB	1.150 E-G	1.318 C-E	**1.411 B**
2	1.035 F-H	0.746 I	0.763 I	**0.848 E**
3	1.668 AB	1.272 D-F	1.431 CD	**1.457 B**
4	1.266 D-F	0.857 HI	0.841 HI	**0.988 D**
5	1.832 A	1.386 C-E	1.542 BC	**1.587 A**
6	1.385 C-E	1.008 GH	0.989 G-I	**1.127 C**
Mean (A)	**1.492 A**	**1.070 B**	**1.0147 B**	
L.S.D. (5%)	**A: 0.15**	**B:0.12**	**AB: 0.22**	

Where:

1: 100% of normal-NPK (100 kg/fed.).
2: 50% of normal-NPK (50 kg/fed.).
3: 75% of normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% of normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% of normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (10): Effect of normal and nano fertilizers on nitrogen content (%) at 70 days from planting of three potato cultivars grown in winter seasons of 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	1.587 DE	1.567 DE	1.490 EF	**1.548 D**
2	1.340 GHI	1.300 HI	1.257 I	**1.299 F**
3	1.797 AB	1.710 BC	1.630 CD	**1.712 B**
4	1.447 FG	1.420 FG	1.367 GH	**1.411 E**
5	1.840 A	1.837 A	1.780 AB	**1.819 A**
6	1.737 ABC	1.657 CD	1.510 EF	**1.634 C**
Mean (A)	**1.624 A**	**1.582 A**	**1.506 B**	
L.S.D. (5%)	**A: 0.045**	**B: 0.038**	**AB: 0.100**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (11): Effect of normal and nano fertilizers on phosphorus content (%) at 70 days from planting of three potato cultivars grown in winter seasons of 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
First season (2023)				
1	0.362 A:G	0.356 A:G	0.350 A:G	**0.356 BCD**
2	0.325 E:G	0.320 FG	0.311 G	**0.318 D**
3	0.397 A:C	0.390 A:D	0.382 A:F	**0.390 AB**
4	0.343 B:G	0.339 C:G	0.332 D:G	**0.338 CD**
5	0.413 A	0.407 AB	0.404 AB	**0.408 A**
6	0.387 A:E	0.376 A:F	0.368 A:G	**0.377 ABC**
Mean (A)	**0.371 A**	**0.365 A**	**0.358 A**	
L.S.D. (5%)	**A: 0.045**	**B: 0.038**	**AB: 0.058**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (12): Effect of normal and nano fertilizers on potassium content (%) at 70 days from planting of three potato cultivars grown in winter seasons of 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
First season (2023)				
1	3.443 F	3.410 F	3.337 G	**3.397 D**
2	3.120 I	3.063 IJ	3.010 J	**3.064 F**
3	3.767 BC	3.730 C	3.667 D	**3.721 B**
4	3.300 G	3.233 H	3.190 H	**3.241 E**
5	3.920 A	3.877 A	3.813 B	**3.870 A**
6	3.623 D	3.553 E	3.503 E	**3.560 C**
Mean (A)	**3.529 A**	**3.478 B**	**3.420 C**	
L.S.D. (5%)	**A: 0.045**	**B: 0.038**	**AB: 0.058**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (13): Effect of normal and nano fertilizers on zinc content (mg/kg) at 70 days from planting of three potato cultivars grown in winter seasons of 2024

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	41.707 J	39.603 K	37.723 L	**39.678 D**
2	37.130 L	35.123 M	34.093 N	**35.449 E**
3	49.133 E	48.423 E	47.250 F	**48.269 B**
4	44.680 H	43.600 I	42.783 I	**43.688 C**
5	53.150 A	52.170 B	50.280 D	**51.867 A**
6	51.167 C	46.537 F	45.553 G	**47.752 B**
Mean (A)	**46.161 A**	**44.243 B**	**42.947 C**	
L.S.D. (5%)	**A: 1.175**	**B: 0.8138**	**AB: 0.3297**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (14): Effect of normal and nano fertilizers on boron content (mg/kg) at 70 days from planting of three potato cultivars grown in winter seasons of 2024.

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	18.707 J	17.937 K	17.340 K	**17.994 E**
2	16.607 L	15.967 M	15.190 N	**15.921 F**
3	23.983 C	23.380 D	22.717 E	**23.360 B**
4	20.813 G	20.077 H	19.367 I	**20.086 D**
5	26.487 A	25.910 A	24.680 B	**25.692 A**
6	25.227 B	22.070 F	21.503 F	**22.933 C**
Mean (A)	**21.971 A**	**20.890 B**	**20.133 C**	
L.S.D. (5%)	**A: 0.630**	**B: 0.239**	**AB: 0.601**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

Table (15): Effect of normal and nano fertilizers on Starch content (mg/g dry weight) at 70 days from planting of three potato cultivars grown in winter seasons of 2024.

Fertilization treatments (B)	Cultivars (A)			Mean (B)
	Lady Rosetta	Cara	Burren	
		First season (2023)		
1	18.707 J	17.937 K	17.340 K	**17.994 E**
2	16.607 L	15.967 M	15.190 N	**15.921 F**
3	23.983 C	23.380 D	22.717 E	**23.360 B**
4	20.813 G	20.077 H	19.367 I	**20.086 D**
5	26.487 A	25.910 A	24.680 B	**25.692 A**
6	25.227 B	22.070 F	21.503 F	**22.933 C**
Mean (A)	**21.971 A**	**20.890 B**	**20.133 C**	
L.S.D. (5%)	**A: 0.630**	**B: 0.239**	**AB: 0.601**	

Where:
1: 100% normal-NPK (100 kg/fed.).
2: 50% normal-NPK (50 kg/fed.).
3: 75% normal-NPK + Nitrolef + Chelated (Zn and B).
4: 50% normal-NPK + Nitrolef + Chelated (Zn and B).
5: 75% normal-NPK + Nano-NPK + Nano (Zn and B).
6: 50% normal-NPK + Nano-NPK + Nano (Zn and B).

REFERENCES

Abd El-Azeim, M.M.; Mohamad, W.S.; Sherif, M.A. and Hussien, M.S. (2019). Influences of nano and non-nano-fertilizers on potato quality and productivity. Minia J. Agric. Res. Develop, 39: 1-31. https://10.21608/mjard.2019.226389

Abdulkadhum, M.H.; Manea, A.I. and Mahmoud, S.S. (2023). Effect of nano potassium spraying and organic fertilization on growth and yield of potato cultivar Sevra. Int. J. Agric. Stat. Sci., 19 (1): 1231-1235. https://www.researchgate.net/publication/376560644

Al-Abdali, R.S.A.; Al-Bayati, H.J.M. and Al-Rashidi, S.M.A. (2021). Response of potato cultivar (Montreal) for different types of chemical and nano fertilizers and their effect on some vegetative growth and yield parameters. Int. J. Agric. Stat. Sci., 17 (2): 687-692. https://connectjournals.com/03899.2021.17.687

Al-Bayati, H.J.; Alabade, A.I.; Al-Khashab, S.M. and Malallah, K.A. (2023). Reducing the chemical fertilizer by nano fertilizers in two varieties of potatoes (*Solanum tuberosum* L.). In IOP Conference Series: Earth and Environmental Science (Vol. 1158, No. 4, p. 042021). IOP Publishing. https://10.1088/1755-1315/1158/4/042021

Al-Bayati, H.J.M.; Al-Jobori, A.K.M. and B.Zaki, Z. (2018). Response of two-potato varieties *Solanum tuberosum* L. to tuber soaking with some treatments in autumn season. III. International Scientific Conference for Agricultural Sciences, Collage of Agriculture, University of Kirkuk, 293-300.

Al-Hayani, A.S. and Sallume, M.O. (2023). Effect of humic acid and the level of nano and traditional nitrogen on the growth and yield of potato. In IOP Conference Series: Earth and Environmental Science (Vol. 1213, No. 1, p. 012014). IOP Publishing.

https://10.1088/1755-1315/1213/1/012014

Al-Juthery, H.W.A.; Al-Taee, R.A.H G.; Al-Obaidi, Z.H.H.; Ali, E.A.H.M. and NAl-Shami, Q.M. (2019). Influence of foliar application of some nano-fertilizers in growth and yield of potato under drip irrigation. In Journal of Physics: Conference Series (Vol. 1294, No. 9, p. 092024). IOP Publishing. https://10.1088/1742-6596/1294/9/092024

Alloway, B.J. (Ed.). (2008). Micronutrient deficiencies in global crop production. Springer Science & Business Media.

Alobaidi, I.E.M. and Ibraheem, F.F. (2024). Effect of spraying zinc on growth and production of two cultivars of potato plant *Solanum tuberosum* L. NTU Journal of Agriculture and Veterinary Science, 4 (3): 152-156. https://doi.org/10.56286/wnm7am75

Al-Selwey, W.A.; Alsadon, A.A.; Ibrahim, A.A.; Labis, J.P. and Seleiman, M.F. (2023). Effects of zinc oxide and silicon dioxide nanoparticles on physiological, yield, and water use efficiency traits of potato grown under water deficit. Plants, 12 (1): 218. https://doi.org/10.3390/plants12010218

Al-Sharifi, A. and Al-Zubaidi, A. (2023). Effect of nano-fertilizer on growth traits of potato cultivars grown under water stress. Euphrates journal of agricultural science, 15 (2): 408-423. https://10.1088/1755-1315/1262/4/042031

Al-Sultan, R.H.; Ibraheem, F.F.; Allela, W.B.; Al-Bayati, H.J. and Salim, N.S. (2023). Effect of N_{20} P_{20} K_{20} nano-fertilizer on quantitative and qualitative yield of two potato cultivars. In IOP Conference Series: Earth and Environmental Science (Vol. 1213, No. 1, p. 012040). IOP Publishing. https://10.1088/1755-1315/1213/1/012040

Al-Taey, D.K.A.; Al-Naely, I.J.C. and Kshash B.H. (2019). A study on effects of water quality, cultivars, organic and chemical fertilizers on potato (*Solanum tuberosum* L.) growth and yield to calculate economic feasibility. Bulgarian Journal of Agricultural Science, 25 (6): 1239-1245.

Al-Zebari, Y.I.; Kahlel, A.S. and Al-Hamdany, S.Y.H. (2021). Response of four potato (*Solanum tuberosum* L.) varieties to four nano fertilizers. In IOP Conference Series: Earth and Environmental Science (Vol. 761, No. 1, p. 012060). IOP Publishing. https://10.1088/1755-1315/761/1/012060

Baddour, A.G. and Masoud, A.S.O. (2022). Response of two potato cultivars to organic fertilization and potassium foliar application. J. of Soil Sciences and Agricultural Engineering, Mansoura Univ. 13 (2): 51-58. https://10.21608/jssae.2022.125730.1063

Chauhan, A.; Pallvi, R.P. and Ludarmani, S.A. (2023). Effect of pre-soaking of potato (*Solanum tuberosum* L.) tubers in nano-urea and nano-zinc on its growth, quality and yield. The Pharma Innovation Journal, 12 (7): 980-995.: https://www.researchgate.net/publication/372337223

Devaux, A.; Goffart, J.P.; Kromann, P.; Andrade-Piedra, J.; Polar, V. and Hareau, G. (2021). The potato of the future: opportunities and challenges in sustainable agri-food systems. Potato Res. 64: 681-720. https://doi.org/10.1007/s11540-021-09501-4

Dhiman, D.; Kalia, A.; Sharma, S.P.; Taggar, M.S. and Dheri, G.S. (2024). Nano-boron foliar application reduced the proportion of cracked tuber yield in potato. Biocatalysis and Agricultural Biotechnology, 58, 103182. https://doi.org/10.1016/j.bcab.2024.103182

Elshamy, M.T.; Husseiny, S.M. and Farroh, K.Y. (2019). Application of nano-chitosan NPK fertilizer on growth and productivity of potato plant. Journal of scientific research in science, 36 (1): 424-441. https://10.21608/jsrs.2019.58522

Elwan, M.W.M.; Elhamahmy, M.A.M. and Mohamed, F.H. (2018). Physiological effect of potato genotypes and salicylic acid on plantlets growth and microtuber production under salt stress. Hortscience Journal of Suez Canal University, 7 (2): 7-14.

Gomez and Gomez (1986). A microcomputer program for the design management and analysis of Agronomic Research Experiments (version 4.0), Michigan State Univ., U.S.A.

Gotteni, A.L.; Verloo, L.G. and Camerlynch, G. (1982). Chemical Analysis of Soil Lap of Analytical and Agro Chemistry, state Univ., Ghent, Belgium.

Hassan, A.A.M. (2003). Potatoes Production. Dar Al-Arabiya Pub. Cairo, Egypt: 446pp.

Hussein, H.A.; Hussein, H.T. and Ali, A.H. (2025). Effect of foliar nutrition and plant detritus on the vegetative growth characteristics of three potato cultivars (*Solanum tuberosum* L.). In IOP Conference Series: Earth and Environmental Science (Vol. 1487, No. 1, p. 012085). IOP Publishing. https://10.1088/1755-1315/1487/1/012085

Janmohammadi, M.; Pornour, N.; Javanmard, A. and Sabaghnia, N. (2016). Effects of bio-organic, conventional and nanofertilizers on growth, yield and quality of potato in cold steppe. Botanica Lithuanica, 22 (2): 133-144. https://10.1515/botlit-2016-0014

Jones, J.; Wolf, B.J.B. and Mills, H.A. (1991). Plant analysis Handbook: A Practical Sampling, Preparation, Analysis, and Interpretative Guide. Micro-Macro Publishing, Athens, Ga.

Kumar, D.; Kumar, R.; Saini, P.K.; Pathak, R.K. and Kumar, R. (2022). Influence of nano fertilizers on growth and yield parameters of potato (*Solanum tuberosum* L.). Biological forum- An International Journal, 14 (4): 1-4. https://www.researchgate.net/publication/382391303

Kumar, P.; Dwivedi, D.K.; Bharati, V.; Tigga, A.; Singh, H. and Dwivedi, A. (2021). Response of NPK on growth and yield of potato (*Solanum tuberosum* L.) under calcareous soils of Bihar. International Journal of Current Microbiology App Science, 10 (02): 1956-1961. https://doi.org/10.20546/ijcmas.2021.1002.234

Mahmood, O.H.; Alnuaimi, J.J.J. and Al-Zubaidi, A.H. (2025a). Biological and nanofertilization effects on growth and yieldrelated traits of spring potato (*Solanum tuberosum* L.). SABRAO Journal of Breeding & Genetics, 57 (1): 241-250. http://doi.org/10.54910/sabrao2025.57.1.23

Mahmood, O.H.; Alnuaimi, J.J.J. and Al-Zubaidi, A.H. (2025b). Role of bio-and nanofertilizers in managing biochemical composition of potato (*Solanum tuberosum* L.). SABRAO Journal of Breeding & Genetics, 57 (1): 294-302. http://doi.org/10.54910/sabrao2025.57.1.29

Mahmoud, A.W.M.; Abdeldaym, E.A.; Abdelaziz, S.M.; El-Sawy, M.B. and Mottaleb, S.A. (2020). Synergetic effects of zinc, boron, silicon, and zeolite nanoparticles on confer tolerance in potato plants subjected to salinity. Agronomy, 10, 19. https://doi.org/10.3390/agronomy10010019

Manea, A.I.; Al-Bayati, H.J. and Al-Taey, D.K.A. (2019). Impact of yeast extract, zinc sulphate and organic fertilizers spraying on potato growth and yield. Res. on Crops, 20 (1): 95-100. https://10.31830/2348-7542.2019.013

Manikanta, B.; Channakeshava, S. and Mamatha, B. (2023). Effect of nitrogen, copper and zinc liquid nano fertilizers on soil properties, nutrient concentration, uptake and nutrient use efficiency of potato (*Solanum tuberosum* L.). Mysore Journal of Agricultural Sciences, 57(1): 127-138.

Marzouk, N.M.; Soliman, M.S.; El-Tanahy, A.M.M. and Mounir, A.M. (2022). Effect of both potassium phosphate and zinc nanocomposites prepared via gamma radiation on growth and productivity of potato under new reclaimed soils. Egyptian Journal of Chemistry, 65 (10): 285-301. https://10.21608/ejchem.2022.115665.5267

Mijweil, A.K. and Muhsin, H.H. (2019). Effect of genotype and nano-fertilizers on some traits and yield of potato. Indian Journal of Ecology, 46 (8): 168-172. https://www.researchgate.net/publication/330324487

Monika, R.H.; Duhan, D.S. and Verma, A. (2024). Enhancing growth and nutrient use efficiency in potato (cv. Kufri Pushkar) through nano urea and zinc sulfate application in Haryana, India. International Journal of Plant & Soil Science, 36 (11): 319-326. https://doi.org/10.9734/ijpss/2024/v36i115147

Moran, R. (1982). Formula determination of chlorophylls pigments extracted with N- dimethyl formamide. Plant Physiology, 69: 1376-1381.

Mousa, T.A.E.; Samar, A.B.; Esmail, H.E.M. and Zaed, G A. (2024). Effect of potassium sources on some potato cultivars grown in sandy soil by using pivot irrigation system. Iraqi Journal of Agricultural Sciences, 55 (3): 1025-1037.

Nizamuddin, M., Mahmood, M.M.; Farooq K. and Riaz, S. (2003). Response of potato to Various Levels of NPK. Asian Journal of Plant Sciences, 2 (2): 149-151.

Peters, I.S.; Combs, B.; Hoskins, I.; Iarman, I.; Kover Watson, M. and Wolf, N. (2003). Recommended Methods of Manure Analysis. Univ. of Wisconsin, Cooperative extension Publ., Madison.

Rahman, M.W.; Islam, M.M.; Sheikh, M.M.; Hossain, M.I.; Kawochar, M.A. and Alam, M.S. (2018). Effect of foliar application of zinc on the yield, quality and storability of potato in Tista meander floodplain soil. Pertanika Journal of Tropical Agricultural Science, 41 (4): 1779-1793.

Rashwan, B.R.; Abd Elhamed, R.S. and Albakry, A.F. (2023). Effect of zinc oxide nanoparticles on growth, chemical composition and yield of potato (*Solanum tuberosum* L.). Journal of Soil Sciences and Agricultural Engineering, 14 (3): 65-71. https://10.21608/jssae.2023.182582.1126

Reddy, B.J.; Mandal, R.; Chakroborty, M.; Hijam, L. and Dutta, P. (2018). A review on potato (*solanum tuberosum* L.) and its genetic diversity. Int. J. Genet. 10, 360. https://doi.org/10.9735/0975-2862.10.2.360-364

Salama, A.N. and Haggag, I. (2024). Impact of lithovit and planting depth on growth, productivity and quality of potato crops. Al-Azhar Journal of

Agricultural Research, 49 (1): 12-25. https://10.21608/ajar.2024.255875.1311

Sarkar, D.; Sheikh, A.A.; Batabyal, K. and Mandal, B. (2014). Boron estimation in soil, plant, and water samples using spectrophotometric methods. Communications in Soil Science and Plant Analysis, 45 (11): 1538-1550.

Sati, K.; Raghav, M. ant Sati, U.C. (2017). Effect of zinc sulphate application on quality of potato. Research on Crops, 18 (1): 98-102.

Singh, B.; Singh, S.K.; Kaur, R. and Rampartap. (2018). Effect of nitrogen, phosphorus and potassium on growth and yield of potato (*Solanum tuberosum* L.). International Journal of Agriculture Sciences, 10 (5): 5319-5321.

Thymanavan, B. and Sadasivam, S. (1984). Quality of Plant and Foods for Human Nutrition; 34: 253.

الملخص العربى

دراسة تأثير التسميد بالأسمدة النانوية أو العادية على إنتاجية وجودة بعض أصناف البطاطس

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في تجربة حقلية، تم اختبار تأثير أسمدة النيتروجين والفوسفور والبوتاسيوم (سواءً التقليدية أو النانوية) وأسمدة الزنك والبوتاسيوم (سواءً المخلبية أو النانوية) على النمو الخضري، والمحصول، وجودة ثلاثة أصناف من البطاطس، وهي: بيرن، وكارا، وليدي روزيتا، على مدار موسمي زراعة متتاليين في عامي 2023 و2024 في مزرعة خاصة بقرية منقطين، - سمالوط، محافظة المنيا، جمهورية مصر العربية. وفيما يلي ملخص للنتائج التي تم الحصول عليها وهي التأثير على المكونات الكيميائية لنبات البطاطس:

1. نتجت أعلى قيم للكلوروفيل أ، والكلوروفيل ب، والكارتونيات، ونسب النيتروجين، والفوسفور، والبوتاسيوم، ومحتوى الزنك والبورون، والنشا من صنف ليدي روزيتا سُمِّد بـ [75% من جرعة السماد التقليدي الموصي NPK (100 كجم/فدان) + سماد NPK النانوي (رش ورقي) + سماد نانوي (زنك وبورون)]. فمن خلال النتائج التي توصلنا إليها،
2. يمكننا أن نستنتج أن اختيار صنف جيد (طبخ أو تصنيع) والتسميد بخليط من العناصر الكبرى والصغرى النانوية والعادية (75% من الموصي به) (النيتروجين، الفوسفور، البوتاسيوم، الزنك، والبوتاسيوم) سيؤدي إلى إنتاجية عالية للبطاطس وجودة عالية للمنتج وتقليل تكاليف الإنتاج.

الكلمات المفتاحية: البطاطس، الأسمدة النانونية والعادية، النمو، جودة المنتج