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# Enhancing productivity of foundation potato seeds produced *in vitro* using organic and mineral fertilizers

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## Abstract

This study was conducted to evaluate whether organic fertilization alone or with some ameliorative substances could replace mineral fertilization in minituber potato production to increase the quantity and quality of *in vitro* produced minitubers of two potato cultivars (Cara and Hermes). Two pot experiments were conducted at the greenhouse of the Regional Research Center located in New Valley Governorate during the winter seasons of 2021/2022 and 2022/2023 in Egypt. The experiment included twelve treatments: 100% compost; 100% seaweed; 100% compost + vinasse; 100% seaweed + vinasse; 75 kg $K_2O$/fed; 100 kg $K_2O$/fed; 120 kg $K_2O$/fed; 50% compost + 50% NPK; 50% seaweed + 50% NPK; 25% compost + 75% NPK+ vinasse; 25% seaweed + 75% NPK+ vinasse; and 25% compost + 75% NPK (control). The treatments were arranged in a Randomized Complete Block Design with three replicates. The results indicated that plant height, average minituber weight, minituber weight/pot and starch content (%) in both seasons, chlorophyll reading in the first season as well as leaf area in the second season, were significantly higher in Cara cv. than Hermes cv., whereas shoot weight in both seasons, chlorophyll reading in the second season as well as stem number of potato plant only in the first season were significantly higher in Hermes cv. than Cara cv. On the other hand, the treatment of 120 kg $K_2O$ caused a significant increment of plant height, leaf area, shoot weight, stem number, starch% and chlorophyll reading, 90 DAP, followed by 100 kg $K_2O$. Moreover, the mixture of 25% compost + 75% NPK+vinasse gave the highest values of tubers number, average minituber weight and minituber weight/pot.

**Key words**: *Solanum tuberosum*, compost, seaweed, vinasse, potassium, growth, yield

## Introduction

Potato (*Solanum tuberosum* L.) is extensively cultivated globally due to its nutritional value, ease of growing, and high yield potential (Wang *et al.*, 2020). Currently, it ranks as the fourth most significant food crop globally, following wheat, rice, and maize, farmed across 19.3 million hectares, yielding 388.2 million tons of potato tubers (Waqas *et al.*, 2021). In 2018, Egypt became the fifth-largest exporter of potatoes, with shipments valued at 205 million US dollars. The nation shipped more than 724,200 metric tons of potatoes, primarily to Russia and the European Union, highlighting the crop's substantial role in Egyptian vegetable exports (El-Basioni and Abd El-Kader, 2024). The planted area for potatoes spans over 212,000 acres with total tuber production reaching approximately 6.91 million tons (FAO, 2021).

Microtubers generated from *in vitro* propagules are small potato tubers ranging from 4 to 12 mm in size, cultivated under regulated laboratory conditions. Minitubers are cultivated in seed potato fields, and the progeny from these plants are propagated in the field for an additional 2 to 5 years before distribution to potato growers.

Numerous studies indicated that a substantial and high-quality potato yield is frequently attained when the soil possesses a light mechanical composition and is enriched with organic fertilizers. Utilizing organic formulations abundant in macro and microelements via extra-root nourishment during the vegetative growth phase may enhance the growth and development of potato plants (Mancer *et al.*, 2024).

Seaweed extracts are extensively utilized in agriculture as plant biostimulants, enhancing plant growth, productivity, and resilience to abiotic and biotic challenges (El-Boukhari *et al.*, 2020). Seaweed and its derivatives encompass a diverse array of natural phytostimulants, including cytokinins, auxins, gibberellins, amino acids, proteins, macro- and micronutrients, osmo-protectants, carbohydrates, and antimicrobial agents, alongside various polysaccharides such as galactans, fucoidan, laminarin, and alginates (Ali *et al.*, 2021). Seaweed extract foliar spray can promote plant growth, enhance flowering and yield, and improve nutritional content, quality, and shelf life (Battacharyya *et al.*, 2015). The beneficial effects are contingent upon the type of seaweed resource, its quality, the content of the extract, as well as the mode of application and concentration (Ali *et al.*, 2021).

Vinasse, or condensed soluble molasses, is a notable product of the fermentation industry. It finds applications in diverse fields, including distillation, food production, sugar processing, and yeast fermentation. In recent years, vinasse has garnered notice for its substantial organic material and natural mineral nutritional content. Its application not only improves agricultural output but also resolves the problem of wastewater management (Carpanez *et al.*, 2022). Furthermore, vinasse increases the accessibility of vital macro and micronutrients, as well as organic matter in the soil, hence enhancing plant growth and yield (Li *et al.*, 2020).

Furthermore, vinasse enhances growth and photosynthetic rates without adverse effects.

This study aimed to improve the growth, quality and productivity of potato foundation seeds by using mineral and/or organic fertilizers.

## Materials and methods

**Plant material and site of experiment**: Microtubers of potato cultivars named 'Cara' and 'Hermes' were used to obtain potato seed material. The effect of some organic and mineral fertilizers on vegetative, tuber yield, and chemical content was investigated during winter seasons of 2021/2022 and 2022/2023 (seeds of potato were planted on 1st week of October in both seasons). *In vitro* plantlets and microtubers of these cultivars were sourced from the Regional Development Center, Academy of Scientific Research and Technology (ASRT), located in New Valley Governorate. Minitubers had an average weight of around 10-14 g and a transverse diameter of 11-13 mm.

**Treatments**: Organic fertilisers were applied at a rate of 8 tonnes per feddan and consisted of a compost mix of animal waste and plant debris (1:1 ratio) obtained from the Desert Research Centre. Seaweed was used at 3 kg per feddan and vinasse at 40 litres per feddan. Consisting of 12 treatments, the experiment was set up in a randomised block design. With three replicates per treatment, seven pots per replicate for each treatment produced a total of 252 pots per cultivar for every season (12 treatments × 7 pots × 3 replicates). Two types of fertilizers—organic and mineral—were used for potato tuber cultivation. The fertilizers were divided into six equal doses, which were applied via irrigation, beginning 15 days after planting, and repeated every 10 days thereafter. The treatments (T1 to T12) were as follows: T1: 100% compost; T2: 100% seaweed; T3: 100% compost + vinasse; T4: 100% seaweed + vinasse; T5: 75 kg $K_2O$/fed; T6: 100 kg $K_2O$/fed; T7: 120 kg $K_2O$/fed; T8: 50% compost + 50% NPK; T9: 50% seaweed + 50% NPK; T10: 25% compost + 75% NPK + vinasse; T11: 25% seaweed + 75% NPK + vinasse; T12: 25% compost + 75% NPK (control).

The mineral fertilizer for potato was 130, and 75 kg $fed^{-1}$ for potatoes as a recommended doses of N and P by the Ministry of Agriculture and Soil Reclamation (MASL) in the forms of ammonium sulfate (20.5 % N) and super phosphate (15 % $P_2O_5$), while K was added at rate of 75, 100 and 120 kg $fed^{-1}$ in form of potassium sulfate (48 % $K_2O$).

**Cultivation of potato seeds**: Two minitubers per pot were planted in the first week of October 2021 and 2022 in plastic pots (30 cm diameter and 40 cm depth). Each pot was filled with 3 kg growth medium composed of a peatmoss, perlite and vermiculite mixture at a volume ratio of 1:2:4. These pots were maintained under greenhouse conditions with natural sunlight conditions. The temperature was maintained at 24 ◦C during the day and 16 ◦C at night, while the relative humidity was around 70-75%.

**Vegetative growth aspects**: A sample of three plants (90 days after planting) was randomly removed from the pots and carried immediately to the laboratory. Plant growth aspects *viz.*, of plant height (cm), leaf area ($cm^2$) of the 3th leaf from the meristem tip was measured by portable leaf area meter (Biovis Leaf Av., Expert Vision Labs Pvt. Ltd., India), shoot weight/ plant (g) and stem number were measured.

**Yield and its components**: 120-day-old plants were harvested and the total tubers were collected, and the number of tubers per plant, average tuber weight (g) and tuber weight/plant were calculated.

**Chemical analysis**: After 90 days from planting, chlorophyll readings were recorded using a Chlorophyll Meter (SPAD). Also, 120 days after planting (DAP), 50 g of tubers from each sample were oven dried at 70 °C until a constant weight and thoroughly ground and stored for chemical analysis of N, P and K %. In order to ascertain the concentrations of N, P, and K in tubers, 0.4 g of crude desiccated powder from each sample was wet digested with a mixture of concentrated sulphuric ($H_2SO_4$) and perchloric ($HClO_4$) acids. The mixture was then heated until it became a clear solution. This solution was quantitatively transferred into a 100 mL measuring vial and stored for subsequent analyses (Cottenie *et al.*, 1982). The total N-determination was conducted using the modified Micro-Kjeldahl apparatus, as outlined by Jones *et al.* (1991). The stannous chloride reduced molybdophosphoric blue colour method in the sulphuric system, as described by Peters *et al.* (2003), was employed to determine total phosphorus spectrophotometrically using the Milton Roy spectronic 120 at a wavelength of 725 nm. The modified method of Peters *et al.* (2003) was employed to estimate the total potassium using a Jenway Flame photometer, Model Corning 400. Also, the method of Anthron reagent, as described by Thymanavan and Sadasivam (1984), was employed to determine starch. Sugars were eliminated from tuber samples, 120 DAP, by treating them with 80% ethanol, and subsequently, starch was extracted using perchloric acid. Starch was hydrolyzed to glucose and hydrated to hydroxymethyl furfural in a hot acidic medium. This compound reacts with anthrone to produce a green product. The photometric estimation of the intensity of the green to dark green colour was conducted at a wavelength of 630 nm. The starch content was determined by multiplying the glucose content in the sample by a factor of 0.9 and utilizing the standard curve.

**Statistical analysis**: The CoSTATE computer software was employed to conduct statistical analyses of all data. The differences between treatment means were compared using the Analysis of Variance (ANOVA) technique, followed by LSD (5%) and Duncan's Multiple Range Test (Gomez and Gomez, 1984).

## Results and discussion

**Plant growth 90 days after planting (DAP)**: Table 1 shows that the Cara cultivar had significantly higher plant height at 90 days after planting (DAP) than Hermes in both growing seasons. However, Hermes had a significant increase in leaf area during the first season, and Cara had a similar increase in the second. Hermes outperformed Cara in terms of shoot weight across both seasons. The number of stems per plant was also significantly higher in Hermes, albeit only during the first season. Seasonal variations between cultivars may be caused by interactions between genotype and environmental conditions during the growth period, reflecting inherent genetic differences between the two varieties.

Data from the same table also indicate that all fertilization treatments had a notable impact on vegetative growth parameters. Compared to the control, the highest mean values for plant height, leaf area, shoot weight, and stem number at 90 DAP were recorded in plants treated with 120 kg $K_2O$, followed by 100 kg

$K_2O$. The difference between these two potassium levels was minimal for most parameters. Similarly, plants treated with a combined organic–mineral mix (25% compost + 75% NPK + vinasse) produced nearly comparable values to those observed with mineral potassium application, with no significant differences across most vegetative traits. This trend was consistent across both seasons.

Cara and Herme had the highest values in all vegetative parameters measured at 90 DAP. Plants treated with the compost-NPK-vinasse mixture produced similar results, with no statistically significant differences from potassium treatments for the majority of traits.

These findings are consistent with previous research. Ali *et al.* (2021) found that high potassium levels significantly increased plant growth, including plant height, most likely due to potassium's role in cell division, elongation, and overall growth processes, as highlighted by Gemmechu (2021).

Compost made from plant and animal waste contains essential nutrients and improves nutrient availability through improved solubility. It also improves soil structure and promotes microbial activity. Before planting, incorporate compost or farmyard manure into the soil to increase fertility and promote plant growth. While the direct effects of chemical fertilisers were not studied separately, compost most likely contributed indirectly to increased plant growth (Priyanka *et al.*, 2020).

Several studies, including Gülsar *et al.* (2019), have shown that NPK fertilisers stimulate vegetative growth by increasing nitrogen, phosphorus, and potassium uptake. Alimkhanov *et al.* (2021) reported that mineral fertilisers significantly increased plant height, stem number, and leaf count in potato plants compared to untreated controls.

Vinasse application may have improved plant biomass and growth by increasing soil osmotic pressure, which enhances nutrient and water uptake (Amin, 2024). Vinasse contains a high concentration of macronutrients and micronutrients, both of which are required for many physiological functions. Its high nitrogen content encourages nitrogen assimilation in photosynthetic tissues, affecting energy flow and carbon partitioning during photosynthesis (Xu *et al.*, 2023). This most likely contributed to increased cell division and elongation, which resulted in greater leaf area and overall vegetative growth (Leghari *et al.*, 2016). Thus, the beneficial effects of vinasse on biomass can be attributed to increased soil nutrient content, particularly nitrogen, phosphorus, and potassium, in the experimental setting.

**Chlorophyll and starch content**: As shown in Table 2, the Cara cultivar had higher leaf chlorophyll content in the first season, but Hermes outperformed Cara in the second season. These seasonal shifts in chlorophyll readings between cultivars could be attributed to genotype-environment interactions, specifically how each variety responds to changing environmental conditions during the growth period.

Potassium fertilisation had a significant influence on chlorophyll content. Plants treated with 120 kg $K_2O$ had the highest chlorophyll values in both seasons compared to the control group (Table 2). Cara plants fertilised with 120 kg and 100 kg $K_2O$ had the highest chlorophyll levels during the first season, while Hermes had the highest values at these potassium levels in the second season. Furthermore,

Table 1. Effect of cultivars, organic or mineral fertilization and those interactions on vegetative growth of potato, 90 DAP, during the seasons of 2021/2022 and 2022/2023.

| Treatments | | Plant height (cm) | | leaf area ($cm^2$) | | Shoot weight/ plant(g) | | Stem number | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2021-22 | 2022-23 | 2021-22 | 2022-23 | 2021-22 | 2022-23 | 2021-22 | 2022-23 |
| Cultivars | | | | | | | | | |
| Cara | | 55.44 | 63.54 | 16.46 | 20.52 | 168.57 | 169.86 | 3.64 | 4.06 |
| Hermes | | 53.04 | 56.65 | 16.96 | 17.33 | 185.14 | 176.76 | 4.19 | 3.96 |
| LSD (5%) | | 0.88 | 1.85 | 0.38 | 0.72 | 1.14 | 0.84 | 0.33 | N.S. |
| Organo-mineral fertilization | | | | | | | | | |
| 1 | | 51.74 | 55.76 | 14.61 | 15.10 | 164.96 | 160.20 | 3.75 | 3.67 |
| 2 | | 49.44 | 53.88 | 13.29 | 12.70 | 151.54 | 143.85 | 3.05 | 2.83 |
| 3 | | 52.35 | 56.67 | 14.99 | 16.25 | 165.57 | 158.90 | 3.80 | 3.74 |
| 4 | | 50.63 | 55.33 | 14.02 | 13.38 | 160.48 | 153.49 | 3.47 | 3.17 |
| 5 | | 55.77 | 63.02 | 18.45 | 20.85 | 187.96 | 188.02 | 4.13 | 4.33 |
| 6 | | 57.92 | 65.33 | 19.63 | 23.70 | 193.70 | 192.03 | 4.26 | 4.79 |
| 7 | | 58.48 | 66.72 | 20.17 | 26.08 | 196.63 | 197.12 | 4.52 | 4.90 |
| 8 | | 54.18 | 58.95 | 16.40 | 18.81 | 179.69 | 176.55 | 3.93 | 3.98 |
| 9 | | 53.32 | 57.83 | 15.53 | 17.76 | 172.99 | 167.43 | 3.83 | 3.83 |
| 10 | | 56.83 | 64.45 | 18.76 | 22.29 | 189.46 | 190.97 | 4.17 | 4.52 |
| 11 | | 54.82 | 60.81 | 17.01 | 19.56 | 178.97 | 173.99 | 4.00 | 4.17 |
| 12 | | 55.41 | 62.33 | 17.67 | 20.65 | 180.33 | 175.65 | 4.05 | 4.21 |
| LSD (5%) | | 2.12 | 4.54 | 0.93 | 1.77 | 2.80 | 2.05 | 0.83 | 0.94 |
| Interactions | | | | | | | | | |
| Cara | 1 | 51.62 | 58.33 | 15.79 | 16.77 | 151.10 | 154.42 | 3.44 | 3.81 |
| | 2 | 50.06 | 55.62 | 15.12 | 13.45 | 128.06 | 129.24 | 2.86 | 2.48 |
| | 3 | 52.54 | 59.57 | 16.02 | 18.42 | 151.63 | 153.04 | 3.52 | 3.86 |
| | 4 | 51.59 | 58.05 | 15.61 | 14.30 | 143.80 | 146.22 | 3.42 | 2.90 |
| | 5 | 57.59 | 67.14 | 17.01 | 21.30 | 186.42 | 188.35 | 3.81 | 4.57 |
| | 6 | 59.49 | 69.81 | 17.35 | 24.51 | 193.32 | 191.31 | 4.00 | 4.95 |
| | 7 | 59.44 | 70.52 | 17.47 | 28.75 | 198.85 | 197.62 | 4.05 | 4.95 |
| | 8 | 55.80 | 63.19 | 16.38 | 20.69 | 174.42 | 175.30 | 3.62 | 4.00 |
| | 9 | 54.22 | 61.57 | 16.13 | 20.26 | 164.25 | 165.84 | 3.57 | 3.95 |
| | 10 | 58.64 | 68.76 | 17.09 | 23.99 | 187.52 | 190.12 | 3.86 | 4.57 |
| | 11 | 56.96 | 63.90 | 16.62 | 21.17 | 170.60 | 172.64 | 3.71 | 4.33 |
| | 12 | 57.38 | 65.95 | 16.90 | 22.63 | 172.80 | 174.25 | 3.76 | 4.38 |
| Hermes | 1 | 51.85 | 53.19 | 13.44 | 13.43 | 178.83 | 165.98 | 4.05 | 3.52 |
| | 2 | 48.81 | 52.14 | 11.46 | 11.95 | 175.01 | 158.47 | 3.24 | 3.19 |
| | 3 | 52.17 | 53.76 | 13.95 | 14.07 | 179.51 | 164.76 | 4.07 | 3.62 |
| | 4 | 49.67 | 52.62 | 12.43 | 12.46 | 177.15 | 160.76 | 3.52 | 3.43 |
| | 5 | 53.95 | 58.90 | 19.88 | 20.39 | 189.50 | 187.69 | 4.45 | 4.10 |
| | 6 | 56.34 | 60.86 | 21.91 | 22.89 | 194.08 | 192.75 | 4.52 | 4.62 |
| | 7 | 57.53 | 62.91 | 22.87 | 23.42 | 194.40 | 196.62 | 5.00 | 4.86 |
| | 8 | 52.55 | 54.71 | 16.41 | 16.92 | 184.95 | 177.80 | 4.24 | 3.95 |
| | 9 | 52.42 | 54.10 | 14.92 | 15.26 | 181.72 | 169.81 | 4.10 | 3.71 |
| | 10 | 55.02 | 60.14 | 20.42 | 20.59 | 191.39 | 191.82 | 4.48 | 4.48 |
| | 11 | 52.67 | 57.72 | 17.40 | 17.95 | 187.34 | 175.34 | 4.29 | 4.00 |
| | 12 | 53.43 | 58.72 | 18.43 | 18.66 | 187.86 | 177.05 | 4.33 | 4.05 |
| LSD (5%) | | 3.05 | 6.42 | 1.32 | 2.51 | 3.96 | 2.91 | 1.17 | 1.34 |

*1- 100% compost; 2- 100% seaweed; 3- 100% compost + vinasse; 4- 100% seaweed + vinasse; 5- 75 kg $K_2O$/fed; 6. 100 kg $K_2O$/fed; 7- 120 kg $K_2O$/fed; 8- 50% compost + 50% NPK; 9- 50% seaweed + 50% NPK; 10- 25% compost + 75% NPK+ vinasse; 11- 25% seaweed + 75% NPK+ vinasse; 12- 25% compost + 75% NPK (control).

plants treated with a combination of 25% compost, 75% NPK, and vinasse—an organo-mineral blend—produced chlorophyll levels closely comparable to those under the mineral potassium treatments, in both Cara and Hermes across the two seasons.

Chlorophyll plays a vital role in photosynthesis, enabling plants to synthesize food and energy. Higher chlorophyll content, as measured by SPAD values, indicates improved photosynthetic efficiency, which can boost overall plant growth and biomass. The increase in chlorophyll following compost application is most likely due to compost's contribution to soil fertility, which promotes better uptake of nitrogen, phosphorus, and potassium—nutrients required for chlorophyll biosynthesis and function (Sharma *et al.*, 2022).

In terms of tuber quality, Table 2 shows that the Cara cultivar consistently produced tubers with a higher starch percentage than Hermes over both seasons. This difference is most likely due to genetic variation between the two cultivars.

The effect of fertilisation treatments on tuber starch content was also visible. Increased potassium application rates resulted in higher starch percentages during both seasons. The most significant improvement was seen in plants treated with 25% compost and 75% NPK plus vinasse, followed by the same treatment without vinasse, both of which outperformed potassium-only fertilisation. These results remained consistent throughout the 2021/2022 and 2022/2023 seasons.

A closer examination of average starch percentages across treatment combinations revealed that organo-mineral fertilisation significantly increased starch accumulation in tubers. The application of 25% compost and 75% NPK with vinasse resulted in the highest starch content, ranging from 20.94% to 20.82% over two seasons, particularly in the Cara variety. The same treatment without vinasse produced a similar, though slightly lower, effect.

Compost's beneficial effect on tuber quality could be attributed to its ability to improve the physiological processes involved in photosynthetic translocation and transformation. Compost aids in the transport of carbohydrates from source leaves to sink organs like tubers, where they are converted into starch, proteins, and vitamins. As a result, adding compost to potato tubers can boost their overall carbohydrate, sugar, and protein content (Koch *et al.*, 2019).

**Potato yield**: Table 3 presents data on the influence of various organic and mineral fertilization treatments on the yield characteristics of potato minitubers for two cultivars over the 2021/2022 and 2022/2023 growing seasons. The assessed parameters include the number of minitubers per plant, average tuber weight, and total tuber weight per plant at 120 days after planting.

The results revealed that the potato cultivar had a significant effect on all yield parameters, although the differences in tuber number and average tuber weight between the two cultivars were not statistically significant during the first season. Across both seasons, the Cara cultivar produced the highest average tuber weights (41.78 g and 46.34 g) and tuber weight per plant (260.59 g and 428.63 g), respectively.

Fertilisation treatments had a significant effect on all yield parameters. During the respective seasons, the combination of

Table 2. Effect of cultivars, organic or mineral fertilization and those interactions on leaves chlorophyll reading, 90 DAP, and starch %, 120 DAP, of potato tubers during the seasons of 2021/2022 and 2022/2023.

| Treatment | | Chlorophyll reading SPAD | | Starch (%) | |
|---|---|---|---|---|---|
| | | 2021/2022 | 2022/2023 | 2021/2022 | 2022/2023 |
| Cultivars | | | | | |
| Cara | | 42.24 | 34.89 | 18.39 | 18.29 |
| Hermes | | 41.56 | 43.23 | 17.46 | 16.99 |
| LSD (5%) | | 0.25 | 0.25 | 0.10 | 0.11 |
| Organo-mineral fertilization | | | | | |
| 1 | | 41.21 | 38.16 | 16.66 | 15.98 |
| 2 | | 40.82 | 37.58 | 14.79 | 15.96 |
| 3 | | 41.35 | 38.26 | 16.93 | 16.45 |
| 4 | | 40.98 | 37.74 | 15.97 | 15.04 |
| 5 | | 42.36 | 39.68 | 17.95 | 17.60 |
| 6 | | 42.92 | 40.61 | 18.85 | 18.64 |
| 7 | | 43.26 | 41.03 | 18.96 | 18.70 |
| 8 | | 41.76 | 38.85 | 17.68 | 17.34 |
| 9 | | 41.43 | 38.63 | 17.44 | 17.08 |
| 10 | | 42.64 | 39.67 | 20.41 | 20.12 |
| 11 | | 41.93 | 39.09 | 19.48 | 19.14 |
| 12 | | 42.17 | 39.42 | 19.99 | 19.69 |
| LSD (5%) | | 0.61 | 0.62 | 0.25 | 0.28 |
| Interactions | | | | | |
| Cara | 1 | 41.61 | 33.91 | 17.09 | 16.88 |
| | 2 | 41.13 | 33.02 | 15.17 | 15.91 |
| | 3 | 41.84 | 33.92 | 17.36 | 17.14 |
| | 4 | 41.35 | 33.14 | 16.38 | 16.16 |
| | 5 | 42.75 | 35.91 | 18.41 | 18.22 |
| | 6 | 43.05 | 36.50 | 19.44 | 19.28 |
| | 7 | 43.22 | 36.72 | 19.45 | 19.30 |
| | 8 | 42.21 | 34.73 | 18.14 | 17.94 |
| | 9 | 41.92 | 34.50 | 17.88 | 17.68 |
| | 10 | 42.92 | 35.89 | 20.94 | 20.82 |
| | 11 | 42.37 | 34.95 | 19.97 | 19.81 |
| | 12 | 42.52 | 35.50 | 20.50 | 20.37 |
| Hermes | 1 | 40.80 | 42.41 | 16.22 | 15.07 |
| | 2 | 40.51 | 42.13 | 14.41 | 16.01 |
| | 3 | 40.86 | 42.60 | 16.51 | 15.76 |
| | 4 | 40.61 | 42.35 | 15.55 | 13.91 |
| | 5 | 41.96 | 43.45 | 17.49 | 16.97 |
| | 6 | 42.78 | 44.71 | 18.27 | 18.00 |
| | 7 | 43.29 | 45.34 | 18.48 | 18.10 |
| | 8 | 41.30 | 42.98 | 17.22 | 16.73 |
| | 9 | 40.94 | 42.77 | 17.00 | 16.47 |
| | 10 | 42.36 | 43.46 | 19.89 | 19.42 |
| | 11 | 41.49 | 43.22 | 18.98 | 18.47 |
| | 12 | 41.82 | 43.33 | 19.48 | 19.00 |
| LSD (5%) | | 4.73 | 0.88 | 0.36 | 0.39 |

* Treatment details are presented beneath Table 1

25% compost, 75% NPK, and vinasse produced the most tubers per plant (7.52 and 11.15), the highest average tuber weight (54.14 g and 49.41 g), and the highest tuber weight per plant (404.65 g and 548.52 g). The treatment with 25% seaweed extract, 75% NPK, and vinasse had the next best performance, producing statistically similar results to the compost-based combination. The treatment consisted of 25% compost + 75% NPK, followed

by 120 kg of $K_2O$. The same pattern continued throughout both seasons.

Interactions between cultivar and fertilization treatment significantly influenced all measured yield components in both years. Notably, Cara fertilized with 25% compost + 75% NPK + vinasse recorded the highest values: 8.00 and 11.33 minitubers per plant, 51.73 g and 50.56 g average tuber weight, and 412.97 g and 571.80 g total tuber weight per plant during the two seasons. Similarly, Hermes under the same treatment showed strong results, with 7.04 and 10.98 tubers per plant, average weights of 56.56 g and 48.26 g, and total tuber weights of 396.32 g and 525.23 g. In most parameters, the difference between cultivars was not statistically significant across both seasons. Other treatments performed moderately. Genetic variation may explain cultivar differences.

Compost is known to improve soil fertility, structure, and nutrient retention. It improves root systems and tuber development by increasing organic matter and nutrients (Gondwe *et al.*, 2020). Organic amendments like compost improve soil quality, resulting in larger, more tubers (Priyanka *et al.*, 2020).

Due to potassium's roles in tuber formation, carbohydrate translocation, and nutrient absorption, mineral potassium fertilisation increased yields. These effects lead to increased tuber size and yield, highlighting potassium's critical role in potato crop productivity and nutritional quality, as reported by El-Sherpiny *et al.* (2022).

Potato yield depends on both tuber number and average tuber size. In addition to total yield, the size distribution of tubers is an important factor for commercial producers and processors. Phosphorus stimulates root cell division and growth, whereas nitrogen promotes vegetative development through cell elongation.

Vinasse application increased yield by improving soil health. Its high concentration of macronutrients and growth-promoting compounds promotes nutrient uptake and internal translocation. Mahmoud *et al.* (2021) found similar results in sweet potatoes, where the combination of organic fertiliser and vinasse significantly increased tuber number, individual tuber weight, and yield per plant and unit area.

**NPK content of tubers**: Table 4 displays the concentrations of nitrogen (N), phosphorus (P), and potassium (K) in potato tubers for the growing seasons of 2021/2022 and 2022/2023. This study assesses the effects of different organic and mineral fertilisation treatments on two potato cultivars and their interactions.

The cultivar had a significant effect on macronutrient concentrations in tubers. Throughout both seasons, the Cara variety had consistently higher nitrogen, phosphorus, and potassium concentrations than Hermes. The observed varietal difference suggests that genetic factors can influence nutrient accumulation in tubers.

The fertilisation treatments significantly influenced the nutrient content of the tubers. The integration of organic and inorganic fertilisers markedly increased the concentrations of nitrogen, phosphorus, and potassium compared to applications of mineral fertilisers alone. The combination of 25% compost, 75% NPK, and vinasse yielded the highest concentrations of nitrogen (1.65% and 2.24%), phosphorus (0.179% and 0.188%), and potassium (1.92% and 1.98%) across the two growing seasons. This was succeeded by an identical treatment omitting vinasse, which similarly yielded relatively high nutrient concentrations.

The combined application of organic materials and mineral

Table 3. Effect of cultivars, organic or mineral fertilization and those interactions on No. of tuber/plant, average tuber weight and tuber weight/plant of potato during the seasons of 2021/2022 and 2022/2023.

| Treatments | | No. of tuber/plant | | Average tuber weight (g) | | Tuber weight g/plant | |
|---|---|---|---|---|---|---|---|
| | | 2021-22 | 2022-23 | 2021-22 | 2022-23 | 2021-22 | 2022-23 |
| Cultivars | | | | | | | |
| Cara | | 6.20 | 9.27 | 41.78 | 46.34 | 260.59 | 428.63 |
| Hermes | | 5.88 | 8.24 | 40.51 | 38.80 | 239.29 | 324.13 |
| LSD (5%) | | N.S. | 0.54 | N.S. | 2.48 | 6.65 | 8.44 |
| Organo-mineral fertilization | | | | | | | |
| 1 | | 5.56 | 8.00 | 32.05 | 36.17 | 177.43 | 288.37 |
| 2 | | 4.60 | 5.67 | 29.13 | 39.61 | 135.38 | 225.87 |
| 3 | | 5.77 | 8.10 | 33.07 | 36.97 | 189.47 | 302.08 |
| 4 | | 5.27 | 7.81 | 32.27 | 34.71 | 166.11 | 273.55 |
| 5 | | 6.01 | 8.79 | 41.79 | 42.37 | 250.42 | 371.88 |
| 6 | | 6.21 | 9.02 | 41.59 | 45.66 | 251.17 | 410.12 |
| 7 | | 6.47 | 9.31 | 43.86 | 48.86 | 278.88 | 452.22 |
| 8 | | 5.81 | 8.57 | 42.62 | 40.47 | 235.67 | 342.25 |
| 9 | | 5.68 | 8.21 | 39.27 | 40.02 | 222.36 | 327.65 |
| 10 | | 7.52 | 11.15 | 54.14 | 49.41 | 404.65 | 548.52 |
| 11 | | 7.08 | 10.38 | 52.55 | 49.87 | 365.83 | 513.32 |
| 12 | | 6.45 | 10.02 | 51.37 | 46.70 | 321.91 | 460.78 |
| LSD (5%) | | 1.06 | 1.32 | 7.67 | 6.09 | 16.29 | 20.67 |
| Interactions | | | | | | | |
| Cara | 1 | 5.62 | 8.71 | 33.39 | 42.20 | 185.91 | 367.23 |
| | 2 | 5.06 | 5.95 | 33.24 | 48.86 | 167.43[1] | 290.53 |
| | 3 | 5.93 | 8.76 | 32.18 | 42.65 | 190.73 | 372.20 |
| | 4 | 5.40 | 8.57 | 33.98 | 40.59 | 182.69 | 345.53 |
| | 5 | 6.21 | 9.38 | 40.82 | 45.41 | 252.33 | 421.70 |
| | 6 | 6.33 | 9.86 | 40.15 | 46.50 | 253.69 | 457.40 |
| | 7 | 6.51 | 9.95 | 44.77 | 48.99 | 291.43 | 487.20 |
| | 8 | 5.87 | 9.00 | 42.48 | 46.94 | 248.03 | 420.07 |
| | 9 | 5.75 | 8.81 | 41.66 | 44.92 | 239.24 | 392.60 |
| | 10 | 8.00 | 11.33 | 51.73 | 50.56 | 412.97 | 571.80 |
| | 11 | 7.24 | 10.71 | 52.87 | 48.61 | 371.69 | 515.37 |
| | 12 | 6.48 | 10.19 | 54.05 | 49.82 | 330.87 | 501.97 |
| Hermes | 1 | 5.51 | 7.29 | 30.70 | 30.15 | 168.95 | 209.50 |
| | 2 | 4.14 | 5.38 | 25.01 | 30.36 | 103.33 | 161.20 |
| | 3 | 5.62 | 7.43 | 33.96 | 31.29 | 188.20 | 231.97 |
| | 4 | 5.14 | 7.05 | 30.55 | 28.82 | 149.53 | 201.57 |
| | 5 | 5.81 | 8.19 | 42.77 | 39.34 | 248.50 | 322.07 |
| | 6 | 6.10 | 8.19 | 43.03 | 44.82 | 248.65 | 362.83 |
| | 7 | 6.43 | 8.67 | 42.94 | 48.74 | 266.32 | 417.23 |
| | 8 | 5.76 | 8.14 | 42.76 | 33.99 | 223.30 | 264.43 |
| | 9 | 5.62 | 7.62 | 36.89 | 35.13 | 205.47 | 262.70 |
| | 10 | 7.04 | 10.98 | 56.56 | 48.26 | 396.32 | 525.23 |
| | 11 | 6.91 | 10.05 | 52.22 | 51.12 | 359.96 | 511.27 |
| | 12 | 6.43 | 9.86 | 48.68 | 43.58 | 312.95 | 419.60 |
| LSD (5%) | | 1.50 | 1.87 | 10.85 | 8.61 | 23.04 | 29.23 |

* Treatment details are presented beneath Table 1

Table 4. Effect of cultivars, organic or mineral fertilization and those interactions on NPK% of potato tuber, 120 DAP, during the seasons of 2021/2022 and 2022/2023.

| Treatments | | N% | | P% | | K% | |
|---|---|---|---|---|---|---|---|
| | | 2021-22 | 2022-23 | 2021-22 | 2022-23 | 2021-22 | 2022-23 |
| Cultivars | | | | | | | |
| Cara | | 1.47 | 1.75 | 0.132 | 0.136 | 1.42 | 1.77 |
| Hermes | | 0.96 | 1.70 | 0.124 | 0.133 | 1.62 | 1.43 |
| LSD (5%) | | 0.02 | 0.02 | 0.003 | 0.003 | 0.02 | 0.03 |
| Organo-mineral fertilization | | | | | | | |
| 1 | | 0.96 | 1.50 | 0.100 | 0.110 | 1.35 | 1.40 |
| 2 | | 0.86 | 1.45 | 0.092 | 0.097 | 1.29 | 1.33 |
| 3 | | 1.06 | 1.54 | 0.106 | 0.112 | 1.39 | 1.44 |
| 4 | | 0.91 | 1.48 | 0.097 | 0.104 | 1.33 | 1.37 |
| 5 | | 1.22 | 1.65 | 0.126 | 0.132 | 1.51 | 1.61 |
| 6 | | 1.32 | 1.67 | 0.135 | 0.143 | 1.54 | 1.67 |
| 7 | | 1.37 | 1.77 | 0.147 | 0.155 | 1.59 | 1.75 |
| 8 | | 1.16 | 1.61 | 0.119 | 0.123 | 1.48 | 1.54 |
| 9 | | 1.09 | 1.59 | 0.111 | 0.118 | 1.41 | 1.51 |
| 10 | | 1.65 | 2.24 | 0.179 | 0.188 | 1.92 | 1.98 |
| 11 | | 1.45 | 2.07 | 0.156 | 0.16 | 1.66 | 1.79 |
| 12 | | 1.51 | 2.15 | 0.166 | 0.173 | 1.76 | 1.88 |
| LSD (5%) | | 0.05 | 0.04 | 0.007 | 0.007 | 0.05 | 0.07 |
| Interactions | | | | | | | |
| Cara | 1 | 1.18 | 1.46 | 0.104 | 0.116 | 1.22 | 1.63 |
| | 2 | 1.05 | 1.39 | 0.097 | 0.100 | 1.16 | 1.58 |
| | 3 | 1.29 | 1.49 | 0.113 | 0.117 | 1.25 | 1.70 |
| | 4 | 1.12 | 1.42 | 0.101 | 0.108[j] | 1.18 | 1.62 |
| | 5 | 1.46 | 1.63 | 0.133 | 0.134 | 1.42 | 1.78 |
| | 6 | 1.59 | 1.66 | 0.137 | 0.143 | 1.47 | 1.82 |
| | 7 | 1.65 | 1.76 | 0.149 | 0.153 | 1.50 | 1.86 |
| | 8 | 1.39 | 1.57 | 0.130 | 0.130 | 1.38 | 1.74 |
| | 9 | 1.32 | 1.54 | 0.119 | 0.124 | 1.27 | 1.74 |
| | 10 | 2.01 | 2.42 | 0.177 | 0.184 | 1.87 | 2.04 |
| | 11 | 1.78 | 2.31 | 0.156 | 0.161 | 1.57 | 1.86 |
| | 12 | 1.82 | 2.38 | 0.164 | 0.166 | 1.70 | 1.90 |
| Hermes | 1 | 0.74 | 1.55 | 0.095 | 0.104 | 1.48 | 1.16 |
| | 2 | 0.66 | 1.50 | 0.087 | 0.094 | 1.42 | 1.08 |
| | 3 | 0.82 | 1.58 | 0.098 | 0.106 | 1.53 | 1.19 |
| | 4 | 0.70 | 1.54 | 0.092 | 0.100 | 1.47 | 1.11 |
| | 5 | 0.98 | 1.68 | 0.120 | 0.130 | 1.60 | 1.43 |
| | 6 | 1.06 | 1.69 | 0.133 | 0.143 | 1.61 | 1.52 |
| | 7 | 1.09 | 1.77 | 0.145 | 0.156 | 1.68 | 1.65 |
| | 8 | 0.94 | 1.66 | 0.108 | 0.116 | 1.58 | 1.33 |
| | 9 | 0.86 | 1.63 | 0.104 | 0.112 | 1.55 | 1.28 |
| | 10 | 1.29 | 2.05 | 0.180 | 0.192 | 1.96 | 1.91 |
| | 11 | 1.13 | 1.84 | 0.156 | 0.168 | 1.75 | 1.72 |
| | 12 | 1.20 | 1.91 | 0.167 | 0.180 | 1.82 | 1.85 |
| LSD (5%) | | 0.07 | 0.06 | 0.009 | 0.009 | 0.08 | 0.09 |

* Treatment details are presented beneath Table 1

fertilisers enhanced tuber nutrient content more effectively than potassium fertilisation alone across both cultivars. The treatment comprising 25% compost, 75% NPK, and vinasse consistently yielded the highest concentrations of N, P, and K, especially in the Cara cultivar, and demonstrated statistical superiority over other treatments. The lowest nutrient concentrations were observed with the treatment of 100% seaweed extract alone. Nonetheless, treatments comprising 25% seaweed extract combined with 75% NPK and 25% compost combined with 75% NPK yielded similar nutrient values in Cara tubers, with no significant differences observed between them.

The improved nutritional status of tubers in compost-based treatments results from compost's capacity to reduce soil alkalinity and enhance cation exchange capacity, which in turn increases nutrient availability. Organic amendments enhance microbial activity, facilitating the solubilisation and absorption of nutrients. The enhancements lead to increased levels of essential nutrients within plant tissues. Compost improves the translocation of photoassimilates from source leaves to tubers by enhancing leaf nutrient status, resulting in improved tuber development. Humic and fulvic acids resulting from compost decomposition are essential for enhancing the availability of soil nutrients for plant uptake. The results align with those presented by Kumari *et al.* (2022).

Potassium is necessary for nutrient transport and uptake in plants. It improves the absorption of phosphorus, calcium, magnesium, and other nutrients. Improved potassium availability may indirectly help the plant accumulate nitrogen and phosphorus. The relationship was apparent in potassium sulphate treatments, which resulted in increased nitrogen and phosphorus concentrations in tubers. El-Sherpiny *et al.* (2022) reported similar findings.

In conclusion, the study showed that both cultivar choice and fertilization strategy played an important role in influencing potato growth, yield, and tuber quality. The cultivar Cara generally performed better than Hermes in terms of plant growth, tuber weight, starch content, and nutrient accumulation. The combination of 25% compost and 75% NPK and vinasse was the best overall way to fertilize. This integrated approach improved vegetative growth, chlorophyll content, yield, and the nutrient status of the tubers. The results show that adding organic matter and mineral fertilizers to soil can make it more fertile and nutrient-rich.

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