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Original Article

Antioxidant capacity in relation to nutrition, stomatal density, and yield of carrot (*Daucus carota* L.) fertilized with bleaching soil compost

Capacidade antioxidante em relação a nutrição, densidade estomática e produtividade da cenoura (*Daucus carota* L.) adubada com composto branqueador de solo

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Abstract

In Peru, oil production is related to the gastronomic boom; consequently, consumption has increased in recent years, which has led to an increase in bleaching earth waste that often lacks proper final disposal. Reason, an investigation was conducted on the antioxidant capacity in relation to the nutrition, stomatal density, and yield of carrots fertilized with bleaching earth-based compost (BEBC). The objective was to determine the antioxidant capacity in relation to the nutritional, stomatal density, and higher yield of the carrot fertilized with BEBC. Methodology was applied with an experimental approach, as the completely randomized block design statistical model was used, with three blocks and five treatments: T_1 with 0, T_2 with 3, T_3 with 3.6, T_4 with 4.2, and T_5 with 4.8 t ha^{-1} of BEBC, applied 30 days after planting. The physical characteristics (total plant length, root size, root diameter, storage root weight, and commercial yield) were evaluated. The concentration of nutrients (nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, iron, manganese, copper, zinc, boron, molybdenum, chlorides, sodium) and the antioxidant capacity of the leaves were determined. The total consumption of nitrogen, phosphorus, and potassium was determined, and the stomatal density in leaves and profitability were evaluated. Results highlighted T_5 in total plant length with 48.76 cm, root size with 16.75 cm, root diameter with 5.03 cm, storage root weight with 238.33 g, and commercial yield with 37.264 t ha^{-1}. Total nitrogen consumption with 183.4 kg ha^{-1}, total phosphorus pentoxide consumption with 52.21 kg ha^{-1}, total potassium oxide consumption with 822.74 kg ha^{-1}, and profitability with 139.8%. T_3 stood out in leaf nutrient analysis with nitrogen, potassium, phosphorus, sulfur, and chlorides. In antioxidant capacity with 3,521.8 µMol trolox 100 g and in stomatal density T_1 with 245 stomata mm^{-2}. It concludes that T^5, with an adequate antioxidant capacity of 2,907.5 µmol Trolox/100 g and a concentration of sulfur, iron, and sodium in leaves associated with a lower stomatal density (110 stomata mm^{-2}), favored the

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efficiency of transpiration, the formation and translocation of carbohydrates to the storage root; moreover, it contributed to the balance of reactive oxygen species (ROS), which strengthened and maximized the crop yield.

Keywords: bleaching soil, compost, nutrition, dosage, antioxidant, yield, carrot.

Resumo

No Peru, a produção de óleo está relacionada com o auge gastronômico; consequentemente, o consumo aumentou nos últimos anos, o que incrementou os resíduos de terra de branqueamento que, frequentemente, não contam com uma disposição final adequada. Razão pela qual se investigou sobre a capacidade antioxidante em relação a nutrição, densidade estomática e rendimento da cenoura fertilizada com composto à base de terra de branqueamento (BEBC). O objetivo foi determinar a capacidade antioxidante em relação a nutricional, densidade estomática e maior rendimento da cenoura fertilizada com BEBC. A metodologia foi aplicada com enfoque experimental, já que se empregou o modelo estatístico de desenho de blocos completamente ao acaso, com três blocos e cinco tratamentos: T1 com 0, T2 com 3, T3 com 3,6, T4 com 4,2 e T5 com 4,8 t ha^{-1} de BEBC, aplicados 30 dias após o plantio. Foram avaliadas as características físicas (comprimento total da planta, tamanho da raiz, diâmetro da raiz, peso da raiz de armazenamento e rendimento comercial). Determinaram-se a concentração de nutrientes (nitrogênio, potássio, fósforo, cálcio, magnésio, enxofre, ferro, manganês, cobre, zinco, boro, molibdênio, cloretos, sódio) e a capacidade antioxidante das folhas. Determinou-se o consumo total de nitrogênio, fósforo, potássio e avaliou-se a densidade de estômatos em folhas e rentabilidade. Resultados destacaram T5 na altura total da planta com 48,76 cm, tamanho da raiz com 16,75 cm, diâmetro da raiz com 5,03 cm, peso da raiz de armazenamento com 238,33 g e rendimento comercial com 37.264 t ha^{-1}. Consumo total de nitrogênio com 183,4 kg ha^{-1}, consumo total de pentóxido de difósforo com 52,21 kg ha^{-1}, consumo total de óxido de potássio com 822,74 kg ha^{-1} e rentabilidade com 139,8%. O T3 destacou-se na análise de nutrientes nas folhas com nitrogênio, potássio, fósforo, enxofre e cloretos. Em capacidade antioxidante com 3.521,8 µMol trolox 100 g e em densidade de estômatos T1 com 245 estômatos mm^{-2}. Conclui que T5, com adequada capacidade antioxidante de 2.907,5 µmol Trolox/100 g e concentração de enxofre, ferro e sódio nas folhas associada a menor densidade estomática (110 estômatos mm^{-2}), favoreceu a eficiência da transpiração, a formação e translocação de carboidratos para a raiz de armazenamento; além disso, contribuiu para o equilíbrio das espécies reativas de oxigênio (ROS), o que fortaleceu e maximizou o rendimento da cultura.

Palavras-chave: clareamento do solo, compostagem, nutrição, dose, antioxidante, rendimento, cenoura.

I. Introduction

Currently, the increase in the global population has intensified the demand for food, which has put pressure on food security. This situation has caused a food deficit due to the shortage or difficulty in acquiring essential nutrition products. This crisis of availability originates from the increase in the costs of inputs necessary for agricultural production. In this regard, Cruz Nieto et al. (2024a) state that the increase in the prices of fertilizers, energy, and other raw materials has caused an economic, food, and social crisis worldwide. According to the latest FAO data, the number of people who cannot afford a healthy diet increased by 112 million, reaching almost 3.1 billion worldwide, which highlights the rise in food prices during the pandemic (FAO, 2022).

In this context, it is noteworthy that the exploitation of natural resources to meet food needs is intensifying. In this case, the edible oils industry is an example, as oil is an essential input for food preparation. Various studies report that these industries have increased production, which implies greater use of inputs and materials in the transformation processes. For this, specific clays are used in the purification and decolorization stages, which generates excessive waste. In this regard, Modiba et al. (2025) mention that the growth of the global population affects the preservation of natural resources by intensifying the demand for land, food, and water, which are essential for survival, resulting in a negative impact considering that we have already surpassed 7.884 billion inhabitants. According to data from the European Palm Oil Alliance (EPOA, 2016), in 2015 the global production of oils (palm, soy, rapeseed, palm kernel, cotton, peanut, corn, coconut, and olive) reached 177.39 million tons. For their part, Hernández and Isturiz (2022) explain that the decolorization of edible oils is processed with acid-activated bentonite, known as bleaching earth, used to reduce the color of fats and oils by adsorbing pigments such as carotenoids and phospholipids, retaining up to 30% of the product.

In this sense, the production of edible oil has increased proportionally with the growth of the global population. This overproduction of edible oil is linked to the increase in the generation of bleaching earth waste, a material whose treatment is limited, which can cause environmental damage. According to Keogh-Brown et al. (2019), vegetable oils are an economical and essential product in food preparation, as their global use has multiplied by 4.5 since 1980. On the other hand, Abdelbasir et al. (2023) point out that spent bleaching earth, a waste product resulting from the refining of vegetable oils, has limited reuse options and a global surplus of approximately two million tons is generated, with considerable volumes in the Middle East, as it is produced in excess there. Likewise, Sunartono et al. (2025) warn that this solid waste is generated during the refining of crude palm oil to obtain edible oil, so if it is not properly disposed of, it can cause environmental damage, as it contains toxic metals and residues of this material.

In Peru, the production of edible oil is directly related to the gastronomic boom, which has led to a significant increase in consumption recently. This increasing production has led to a rise in bleaching earth waste, which in many cases does not have proper final disposal. Regarding consumption levels, Vilar et al. (2018) indicate that per capita consumption is 0.104 liters, while Rodríguez (2013) reports an average family consumption of 2.26 liters per month and 8.46 liters per year per person. Given this high demand, Carbajal (2022) states that the Ministry of Environment of Peru generates more than seven million tons of solid waste per year, of which six thousand tons correspond to residual clay, and there are only 64 authorized landfills, which is insufficient for such a volume.

Therefore, it is necessary to promote sustainable alternatives, such as the production of BEBC, since it contains nutrients and, when applied to the soil, improves its physical, chemical, and biological properties. In this way, it promotes the reduction of production costs, increases crop yields, and decreases environmental damage. In this regard, Vélez Chang (2024) highlights that the BEBC has a pH of 5, electrical conductivity (EC) of 3.8 mS/cm, moisture content of 4.70%, organic matter of 52.40%, nitrogen of 1.2%, P_2O_5 of 0.96%, K_2O of 1.18%, CaO of 7.25%, MgO of 1%, and C/N ratio of 37.99%. In this same vein, Cheong et al. (2013) state that the formulation of decolorizing earth with agricultural biomass improved the balance of N, P, K nutrients, the C:N ratio, and the pH of the bioorganic fertilizer, which is appropriate as it enhances soil properties and promotes the growth and yield of eggplant. Complementarily, Sinaga et al. (2021) determined that NPK fertilization with 5% clay mineral plus 5% spent or de-oiled bleaching earth has the same nutritional effect as NPK with 10% clay mineral on plant yield.

It is worth noting that the application of BEBC provides nutrients and microorganisms that enhance the availability of elements for absorption by the plant, in this case, the carrot. As a result, these nutrients optimize transpiration, photosynthesis, the formation and translocation of carbohydrates to the storage root, and other physiological processes. Likewise, they are involved in the formation of antioxidant enzymes and compounds related to antioxidant capacity. These compounds enhance stress fortification, resulting in good development and, consequently, in higher yield of the crop. In agreement, Cruz Nieto et al. (2025b) indicate that the addition of BEBC provided essential nutrients that improved their absorption by the plants, optimizing photosynthesis and the translocation of carbohydrates to the reserves, which strengthened them against stress and improved performance. Complementarily, Ait-El-Mokhtar et al. (2020) report that, under the stress suffered by the plant due to the presence of sodium chloride in the soil, the combined application of compost and arbuscular mycorrhizal fungi maximized growth, stomatal conductance, leaf water potential, the activity of all antioxidant enzymes, and the absorption of phosphorus, potassium, nitrogen, and calcium, as well as the content of proline and soluble sugars.

The BEBC contributes to the synthesis of antioxidant enzymes, secondary metabolites, and beta-carotene. The enzymes act at the cellular level, and many metabolites, such as flavonoids and vitamins, are found in the cytoplasm, where they are stored in vacuoles, while beta-carotene accumulates in the chromoplasts. Together, these compounds integrate the antioxidant system, which acts as an electron donor that balances the ROS caused by nutritional, environmental, and pest stress. According to Mishra et al. (2023), this balance between the production and elimination of ROS is maintained through enzymatic antioxidant mechanisms, such as ascorbate peroxidase (APX), superoxide dismutase (SOD), catalase (CAT), and glutathione reductase (GR), and non-enzymatic mechanisms, such as liposoluble antioxidants (α-tocopherol and β-carotene) and water-soluble antioxidants (glutathione, ascorbic acid, etc.). Complementarily, Vicidomini et al. (2024) highlight that plants have developed antioxidant mechanisms with enzymes that eliminate ROS and reduce their harmful effects, in addition to the synthesis of non-enzymatic compounds, such as flavonoids, phenolic acids, and vitamins, which effectively neutralize them and regenerate other antioxidants, offering broad protection against oxidative stress. For their part, Prasad and Shivay (2020) explain that nitrogen fertilization can increase the carotene content in carrots, while Almagro et al. (2022) mention that β-carotene functions as an antenna pigment and antioxidant in plants, providing them protection against photooxidative damage caused by ultraviolet type B light.

For this reason, the antioxidant capacity in relation to nutrition, stomatal density, and yield of carrots fertilized with BEBC was investigated. The objective was to determine the antioxidant capacity in relation to nutritional, stomatal density, and higher yield of the carrot fertilized with BEBC. Therefore, the statistical model of a completely randomized block design was employed, consisting of 3 blocks and 5 treatments, which included the standard dose and the control.

2. Methodology

2.1. Location of the experiment

The experiment was conducted in the populated center of Chilampa, in the district of Végueta, in the province of Huaura, in the region of Lima. The coordinates of the experiment were south latitude, 10° 56' 12.355"; west longitude, 77° 38' 12.682". Regarding the climatic conditions, the temperature ranges between 20 and 24 °C, the relative humidity is between 73 and 80%, and the average probability of precipitation is 10%.

2.2. Type of research

This is applied research with an experimental approach, as evaluating the carrot samples provided data on their physical characteristics, which were processed through statistical analysis to determine the appropriate dose of BEBC. This dose will be recommended to the farmers in the area.

2.3. Population

It refers to the carrot plants that develop in the Végueta district, situated between 0 and 150 meters above sea level. Therefore, once the results of the experiment were obtained, they were validated.

2.4. Sample

Regarding the sample, 50% of the carrot plants were randomly selected, and those in the central twin rows were marked with tape. This procedure was carried out with the aim of avoiding edge effects in each plot. These plants were evaluated for their physical characteristics until harvest, and leaf samples were taken for chemical and biological analyses.

2.5. Study factor

To determine the standard dose of BEBC in carrot cultivation, the results of the soil analysis and the amount of fertilizer that farmers in the area apply to this crop, which is between 3 and 4 t/ha, were considered. For their part, Hirzel and Salazar (2016) recommend applying between 4 and 8 t ha^{-1} of compost made from chicken manure, poultry, straw, or other materials with a high C/N ratio. Therefore, a dose of 3.6 t ha^{-1} of BEBC was established, which was applied only once. Table 1 presents, in detail, the doses for each treatment.

2.6. Calculation of the amount of nitrogen in the soil

To calculate the amount of nitrogen in the soil, the following procedures were carried out.

2.6.1. Determination of the weight of the arable soil layer

To determine the weight of the soil, the depth of the arable layer and the bulk density have been taken into account, as stated by Ipanaqué (2023). Below, the Formula 1 for calculating the weight of the arable layer of the soil is detailed.

Formula for the weight of the arable layer.

$$\left[Weight\ ha\right] = \left(\text{Soil Depth}\right)\left(Apparent\ s.d.\right)\left(Ha\right) \quad (1)$$

where: Weight ha: Soil weight per hectare (3,500 t ha^{-1} of soil); Soil Depth: Soil depth (0.25 m.); Apparent s.d.: Apparent soil density (1.4 g cm^{-3}); Ha: Hectare (10,000 m^2).

2.6.2. Determination of organic carbon

The next step was to determine the organic carbon, for which the value of the soil organic matter was taken into account and multiplied by a conversion factor (Vela et al., 2012). The Formula 2 for organic carbon is detailed below.

Formula of organic carbon.

$$\left[C.Org.\right] = \left[\left(OM\right)\left(0.58\right)\right] \quad (2)$$

where: C.Org.: Organic carbon (1.276%); O.M.: Organic matter (2.2%) (See Table 2) (INIA, 2025a).

2.6.3. Determination of the C/N ratio

To determine the value of the soil C/N ratio, the Formula 3 detailed below was used.

Formula for the C/N ratio

$$\frac{C}{N} = \frac{\left[\left(OM\right)\left(0.58\right)\right]}{N} \quad (3)$$

where: N: Soil nitrogen (0.1%) (see Table 2) (INIA, 2025a); OM.: Organic matter (2%) (see Table 2) (INIA, 2025a); C/N: Carbon to nitrogen ratio (11.6).

Once the C/N ratio was obtained, which is 11.6, it was taken as an indicator within the range of that ratio (i.e., between 10 and 12), which is equivalent to 140 ppm of nitrogen in the soil (see Table 3).

After setting the amount of 140 ppm of nitrogen in the soil indicated in Table 3, the formula to calculate the available nitrogen (AN) was applied. This formula consists of multiplying 140 ppm by 0.1% of the soil nitrogen (see Table 2) (INIA, 2025a), resulting in 14 ppm of AN. Next, this amount was projected over the weight of the arable layer (3,500 t/ha), resulting in 49 kg/ha of soil available nitrogen (SAN).

2.7. Determination of the standard dose of BEBC in relation to nitrogen

To determine the standard dose of BEBC, the following steps were followed:

For this, the amount of nitrogen from the nutritional recommendation obtained at INIA-Hural, which is 150 kg ha^{-1} (see Table 4) (INIA, 2025b), was taken. This value was

Table 1. BEBC doses for carrot cultivation.

Treatment	Dose of BEBC (t ha^{-1})
T_1	0
T_2	3
T_3	3.6
T_4	4.2
T_5	4.8

Table 2. Soil analysis of the experimental area.

N° Lab.	E.C. 1:2:5 dS/m	pH 1:2:5	O.M. (%)	N (%)	P (ppm)	K (ppm)	$CaCO_3$ (%)	Cation exchange (mEq/100 g of soil)				C.E.C
								Ca	Mg	Na	K	
091534-25/SU/DO	0.702	8.00	2	0.1	3.4	192.78	4.7	6.77	1.81	0.96	0.49	10.03

Note: C.E.C. = Cation Exchange Capacity; E.C. = Electrical Conductivity. Source: INIA (2025a).

subtracted from the 49 kg of SAN, resulting in an applied available nitrogen (NDA) of 101 kg ha^{-1}.

Next, the amount of 2.8% of the nitrogen from BEBC was taken (see Table 5) (INIA, 2025c). This amount was projected for doses of 0, 3, 3.6, 4.2, and 4.8 t ha^{-1} of BEBC (see Table 1), resulting in 0, 84, 100.8, 117.6, and 134.4 kg ha^{-1} of nitrogen respectively.

Finally, the 101 kg ha^{-1} of SAN (obtained from the difference between the nitrogen in the nutritional recommendation and the soil) was compared with the nitrogen projection of the BEBC corresponding to 3.6 and 4.2 t ha^{-1}, which results in 100.8 and 117.6 kg ha^{-1}, respectively. Therefore, it is concluded that the standard dose is 100.8 kg ha^{-1} of nitrogen, which is equivalent to 3.6 t ha^{-1} of BEBC.

2.8. Calculation of the amount of phosphorus in the soil

To determine the calculation of diphosphorus pentoxide (P_2O_5) in the soil, the following procedures were carried out.

2.8.1. Determination of the weight of the arable soil layer

To calculate the weight of the arable soil layer, its depth, bulk density, and area have been taken into account, as mentioned by Ipanaqué (2023). Below, the Formula 4 for performing this calculation is detailed.

Formula for the weight of the arable layer of the soil.

$$\left[Weight\ ha\right]=\left(\text{Soil Depth}\right)\left(Apparent\ s.d.\right)\left(Ha\right) \tag{4}$$

where: Weight ha: Soil weight per hectare (3,500 t ha^{-1} of soil); Soil Depth: Soil depth (0.25 m.); Apparent s.d.: Apparent soil density (1.4 g cm^{-3}); Ha: Hectare (10,000 m^2)

2.8.2. Determination of phosphorus in the soil

After obtaining the weight of the arable layer of the soil, which is 3,500 t ha^{-1}, it was projected using the P2 from the soil analysis, as mentioned by Bello and Pino (2000). Next, the Formula 5 for projecting the weight of the arable layer with soil phosphorus is detailed.

Formula for projecting the weight of phosphorus in relation to the weight of the arable layer.

$$\left[Weight\ P_2\left(kg\ ha^{-1}\right)\right]=\frac{\left[Weight\ S.\left(kg\ ha^{-1}\right)\right]\left[Weight\ P_2\ S.\left(mg\right)\right]}{1kg} \tag{5}$$

where: *Weight* P_2. (kg ha^{-1}): Weight of phosphorus (11.9 kg ha^{-1} of P_2); Weight S. (kg ha^{-1}): Weight of the soil (3,500,000 kg ha^{-1} of soil); Weight P_2 S (mg kg^{-1}): Weight of phosphorus in soil (3.4 mg kg^{-1} of P2) (See Table 2) (INIA, 2025a).

2.8.3. Determination of P_2O_5 in the soil

To obtain the amount of P_2O_5 in the soil, the weight of phosphorus in kg ha^{-1} and the number of moles of P_2 and P_2O_5 were taken into account, as stated by Carrasco and Aguirre (2023). Below, the Formula 6 for projecting P_2 to P_2O_5 kg ha^{-1} is detailed.

Formula to project P_2 to P_2O_5 kg ha^{-1}.

$$\left[W.P_2O_5\left(kg\ ha^{-1}\right)\right]=\frac{\left[N\ moles\ P_2O_5\right]\left[W.P_2\ kg\ ha^{-1}\right]}{\left[N\ moles\ P_2\right]} \tag{6}$$

where: W. P_2O_5 (kg ha^{-1}): Weight of P_2O_5 (27.25 kg ha^{-1} of P_2O_5); N moles P_2O_5: Number of moles of P_2O_5 (142 moles of P_2O_5); N moles P_2: Number of moles of P_2 (62 moles of P_2); W. P_2 (kg ha^{-1}): Weight of phosphorus (11.9 kg ha^{-1} of P_2).

2.9. Determination of potassium in the soil

To determine the potassium oxide (K_2O) in the soil, the following procedures were carried out.

Table 3. Conversion factor from total nitrogen to available nitrogen in relation (C/N).

C/N Ratio Range	Conversion of total nitrogen percentage (T.N.) nitrogen to (ppm)
Greater than 12	11.2
10 to 12	140
Less than 10	225

Source: Kass (1998).

Table 4. Recommended macronutrients for carrot cultivation.

Nutrients (kg ha^{-1})		
N	P	K
150	80	60

Source: INIA (2025b).

Table 5. Chemical Analysis of BEBC.

N° Lab.	ID Sample	pH	E.C. (mS cm^{-1})	Humidity (%)	O.M. (%)	N (%)	P_2O_5 (%)	K_2O (%)	CaO (%)	MgO (%)	C/N
AO205-DO-24	Fertilizer	4.6	3.4	12.8	50.7	2.8	0.52	0.20	0.90	0.44	18.11

Source: INIA (2025c).

2.9.1. Determination of the weight of the arable soil layer

To calculate the weight of the arable layer, the depth, the bulk density of the soil, and the area were taken into account, as stated by Ipanaqué (2023). Below, the Formula 7 for performing this calculation is detailed.

Formula for the weight of the arable layer

$$\left[Weight\ ha\right]=\left(\text{Soil Depth}\right)\left(Apparent\ s.d.\right)\left(Ha\right) \quad (7)$$

where: Weight ha: Soil weight per hectare (3,500 t ha^{-1} of soil); Soil Depth: Soil depth (0.25 m.); Apparent s.d.: Apparent soil density (1.4 g cm^{-3}); Ha: Hectare (10,000 m^2).

2.9.2. Determination of potassium in the soil

Once the weight of the arable layer, which is 3,500 t ha^{-1}, was obtained, the projection was made with K2, which was obtained from the soil analysis, as stated by Toledo (2016). Next, the projection of the weight of the arable layer in relation to the potassium content of the soil is detailed.

Formula 8 for projecting the weight of potassium in relation to the weight of the arable layer.

$$\left[W.K_2\left(kg\ ha^{-1}\right)\right]=\frac{\left[W.S.\left(kg\ ha^{-1}\right)\right]\left[W.K_2\ in\ S.\left(mg\right)\right]}{1\,kg} \quad (8)$$

where: $W.K_2$. (kg ha^{-1}): Weight of potassium (674.73 kg ha^{-1} of K_2); W.S. (kg ha^{-1}): Weight of the soil (3,500,000 kg ha^{-1} of soil); $W.K_2$ in S. (mg kg^{-1}): Weight of potassium in soil (192.78 mg kg^{-1} of K_2) (See Table 2) (INIA, 2025a).

2.9.3. Determination of K_2O in the soil

In this process, the weight of potassium in the soil (kg ha^{-1}) and the number of moles of K_2 and K_2O, data mentioned by Toledo (2016), have been taken into account. Below, the Formula 9 for projecting K_2 to K_2O in kg ha^{-1} is detailed.

Formula to project K_2 to K_2O kg ha^{-1}.

$$\left[W.K_2O\left(kg\ ha^{-1}\right)\right]=\frac{\left[N\ moles\ K_2O\right]\left[W.K_2\ kg\ ha^{-1}\right]}{\left[N\ moles\ K_2\right]} \quad (9)$$

where: $W.K_2O$ (kg ha^{-1}): Weight of K_2O (813.14 kg ha^{-1} of K_2O); N moles K_2O: Number of moles of K_2O (94 moles of K_2O); N moles K_2: Number of moles of K_2 (78 moles of K_2); W. K_2 (kg ha^{-1}): Weight of potassium (674.73 kg ha^{-1} of K_2).

2.10. Statistical analysis

2.10.1. Statistical analysis for the data on the physical characteristics of the carrot

2.10.1.1. Analysis of variance

Once the data on the physical characteristics of the carrot were obtained, they were processed using analysis of variance to determine if there were significant differences between the treatments (the calculated F was greater than the tabulated F), that is, if the application of BEBC had any effect. To do this, the tabulated F data were obtained from Fisher's table with a 5% error. The coefficient of variation was also determined, which allowed for the evaluation of whether there was variation in the averages of the plots.

2.10.1.2. Duncan's test

Next, the data on physical characteristics were processed using the Duncan test with a 5% error level, which classified and grouped the treatment averages into letters. In this way, it was determined whether there was statistical differentiation when the letters were different or not. It was also determined which treatment stood out compared to the others.

2.10.2. Statistical analysis to determine total nitrogen consumption

The total nitrogen consumption for carrots was determined by taking 2.8% nitrogen from the BEBC (see Table 5) (INIA, 2025c), and projecting it to the doses of 0, 3, 3.6, 4.2, and 4.8 t ha^{-1} of the fertilizer indicated in Table 1. Thus, 0, 84, 100.8, 117.6, and 134.4 kg ha^{-1} of nitrogen were obtained. Subsequently, these values were added to the soil nitrogen (49 kg ha^{-1}), resulting in 49, 133, 149.8, 166.6, and 183.4 kg ha^{-1} of nitrogen. Finally, the treatments were arranged from lowest to highest in a table along with their mentioned results, antioxidant capacity, and commercial yields, which allowed for their interpretation and analysis (see Table 6).

2.10.3. Statistical analysis to determine the total consumption of P_2O_5

The total phosphorus consumption for carrot cultivation was calculated using the P_2O_5 from the fertilizer, which is 0.52% (see Table 5) (INIA, 2025c), and projected to the doses of 0, 3, 3.6, 4.2, and 4.8 t ha^{-1} of BEBC indicated in Table 1. This resulted in 0, 15.6, 18.72, 21.84, and 24.96 kg ha^{-1} of P_2O_5, respectively. These amounts were added to the soil's P_2O_5, which is 27.25 kg ha^{-1}, resulting in 27.25, 42.85, 45.97, 49.09, and 52.21 kg ha^{-1} of P_2O_5, respectively. Finally, the doses of the treatments were arranged from lowest to highest along with the aforementioned results, antioxidant capacity, and commercial yield, which allowed for their interpretation and analysis (see Table 7).

2.10.4. Statistical analysis to determine the total K_2O consumption

The total potassium consumption of the soil was determined taking into account the K_2O of the BEBC, which is 0.20% (see Table 5) (INIA, 2025c). This value was projected for the doses of 0, 3, 3.6, 4.2, and 4.8 t ha^{-1} of said fertilizer indicated in Table 1. This resulted in 0, 6, 7.2, 8.4, and 9.6 kg ha^{-1} of K_2O. Next, these values were added to the soil potassium, which is 813.14 kg ha^{-1} of K_2O, resulting in 813.14, 819.14, 820.34, 821.54, and 822.74 kg ha^{-1} of K_2O, respectively. Finally, the treatments were placed and ordered from lowest to highest in a table along with their mentioned results, antioxidant capacity, and commercial yield for interpretation and analysis (see Table 8).

2.11. Techniques and instruments for data collection

2.11.1. Data collection techniques on carrot characteristics

To collect data on the characteristics of the carrot, observation and measurement techniques were employed for its physical, chemical, and biological characteristics (Hernández Mendoza and Duana Avila, 2020). For this purpose, measuring instruments such as a digital scale, a measuring tape, and a caliper were used. The nutrient concentrations in the leaves were determined using the equipment from the AGQ Perú S.A.C. laboratory, and the antioxidant capacity was quantified with materials from the Nutritional Research Institute (IIN) laboratory. Finally, to quantify the stomata, the Quanta scanning electron microscope was used.

2.11.2. Techniques to determine antioxidant capacity

The determination of the antioxidant capacity of carrot leaves was carried out using the ABTS assay (2,2'-azinobis (3-ethylbenzothiazoline-6-sulfonic acid)), a simple and widely used method to measure and neutralize the cation radical (Mejía-Reyes et al., 2021). Also, the DPPH assay (2,2-diphenyl-1-picrylhydrazyl), which is simple and more

Table 6. Total nitrogen consumption in relation to antioxidant capacity.

Treatment	Dose of BEBC (kg ha^{-1})	*BEBC Nitrogen (kg ha^{-1})	Soil nitrogen (kg ha^{-1})	Total nitrogen consumption (Kg ha^{-1})	Antioxidant capacity (μMol trolox 100 g)	Commercial yield (t ha^{-1})
T_1	0	0	49	49	2,368.9	31.875
T_2	3,000	84	49	133	3,349.4	35.376
T_3	3,600	100.8	49	149.8	3,521.8	38.410
T_4	4,200	117.6	49	166.6	2,706.8	40.965
T_5	4,800	134.4	49	183.4	2,907.5	42.264

***Note:** The nitrogen from the BEBC, which is 2.8% (see table 5) (INIA, 2025c), was taken and projected to 4,800 kg ha^{-1} of BEBC, resulting in 134.4 kg ha^{-1} of nitrogen. This procedure was also carried out for the other treatments indicated in Table 1.

Table 7. Total consumption of phosphorus pentoxide in relation to antioxidant capacity.

Treatment	Dose of BEBC (kg ha^{-1})	*P_2O_5 from BEBC (kg ha^{-1})	P_2O_5 in the soil (kg ha^{-1})	Total P_2O_5 consumption (Kg ha^{-1})	Antioxidant capacity (μMol trolox 100 g)	Commercial yield (t ha^{-1})
T_1	0	0	27.25	27.25	2,368.9	31.875
T_2	3,000	15.60	27.25	42.85	3,349.4	35.376
T_3	3,600	18.72	27.25	45.97	3,521.8	38.410
T_4	4,200	21.84	27.25	49.09	2,706.8	40.965
T_5	4,800	24.96	27.25	52.21	2,907.5	42.264

***Note:** The P_2O_5 from the BEBC, which is 0.52% (see table 5) (INIA, 2025C), was taken and projected to 4800 kg ha^{-1} of BEBC, resulting in 24.96 kg ha^{-1} of P_2O_5. This procedure was also carried out for the other treatments indicated in Table 1.

Table 8. Total potassium oxide consumption in relation to antioxidant capacity.

Treatment	Dose of BEBC (kg ha^{-1})	*K_2O from BEBC (kg ha^{-1})	Soil K_2O (kg ha^{-1})	Total K_2O consumption (kg ha^{-1})	Antioxidant capacity (μMol trolox 100 g)	Commercial yield (t ha^{-1})
T_1	0	0	813.14	813.14	2,368.9	31.875
T_2	3,000	6.0	813.14	819.14	3,349.4	35.376
T_3	3,600	7.2	813.14	820.34	3,521.8	38.410
T_4	4,200	8.4	813.14	821.54	2,706.8	40.965
T_5	4,800	9.6	813.14	822.74	2,907.5	42.264

***Note:** The K_2O from the BEBC, which is 0.20% (see Table 5) (INIA, 2025c), was taken and projected to 4,800 kg ha^{-1} of BEBC, resulting in 9.6 kg ha^{-1} of K_2O. This procedure was also carried out for the other treatments indicated in Table 1.

commonly used, was employed to reduce the free radical with Trolox as the antioxidant, diluted with reagents such as ethanol, carbonates, and distilled water; the decrease in absorbance is measured by spectrophotometry in the visible region (Dorantes-Salazar et al., 2023). The percentage of inhibition can be calculated using the Equation 10 presented in various studies, such as that of Almanza Gámez et al. (2024).

Formula to determine percentage inhibition.

$$\%\ \text{Inh.} = \frac{\left(ABTS_{t=0} - ABTS_{t=6}\right)}{ABTS_{t=0}} * 100 \quad (10)$$

where: % Inh.: Percentage of inhibition; ABTS $_{(t=0)}$: Absorbance obtained at time zero; ABTS $_{(t=6)}$: Absorbance after 6 minutes.

Then, the expression according to the TEAC-DPPH method used to determine antioxidant capacity was applied, as described by Gutiérrez Rodas (2022).

Formula 11 to determine antioxidant capacity.

$$C.A.\left(\mu\text{mol TROLOX eq.}/\text{g}\right) = Y\frac{\left(W+V\right)}{W} * Fd \quad (11)$$

where: C.A.: Antioxidant capacity; Y: µmol (Micromole); W: Sample weight (g); V: Solvent volume (mL); Fd: Dilution factor.

2.11.3. Techniques for determining soil nutrients

To analyze the elements present in the soil, a representative sample of 1 kg of soil was taken to the INIA-Huaral laboratory, where different techniques were employed for its study. To determine the pH of the soil and the residues, method 9045D was used. To determine the amount of organic matter, the Walkley-Black AS-07 method was used, and this result allowed for the determination of the nitrogen content. To determine the amount of phosphorus, the Olsen method was used, and for potassium, the calcium carbonate technique (acid neutralization method AS-29) was applied. Finally, to calculate the number of microelements such as calcium, magnesium, sodium, and potassium, ammonium acetate was used.

2.12. Procedures

To prepare the BEBC, 33% bleaching soil, 33% guinea pig guano, and 33% dry grass were used. These materials were left to compost in a pit 1 meter deep, 1.5 meters long, and 1 meter wide. During the first month, three washings were carried out with an average of 20 liters of water every 10 days; in the second and third months, it was washed twice and turned. This process continued until the fourth month, until the compost was mature. That is, it should be dark in color, odorless, and granular.

Then, the land was prepared as the farmers of the Vegueta district in the province of Huaura do. Afterward, 20 soil sub-samples were taken using the zigzag method, covering the entire experimental field to a depth of 0.25 m. Next, the 20 sub-samples were mixed on a blanket, and a representative sample of 1 kg was taken, which was sent to the INIA-Huaral laboratory to determine its chemical characteristics.

On June 21, 2026, carrot seeds with a high germination percentage, varietal purity, and no damage were used. For this purpose, a portable seed drill was used, which sowed in a continuous stream and at 0.60 m between twin furrows. Afterward, a heavy irrigation was carried out, and four days later, a light irrigation, totaling 5-6 irrigations per month, depending on the soil and climate. In addition, two weeding sessions were carried out per month. It is also indicated that the treatment had a length of 4 m, a width of 1.2 m, and a separation between block streets of 0.5 m.

At 30 days after planting, the thinning was carried out throughout the experimental area, leaving one plant every 0.10 m, and subsequently, the doses of BEBC indicated in Table 1 were applied all at once. Then, the physical characteristics of the plant were evaluated until October 18, 2026. Once the data was obtained, it was processed through statistical analysis.

During the harvest, samples of undamaged and fresh leaves were randomly taken from the carrot blocks, without repeating the treatments. These samples were taken to the AGQ Perú SAC laboratory to determine the nutrient concentration. Similarly, samples from the five treatments were taken to determine the antioxidant capacity at the IIN, and another five representative leaf samples were taken to the laboratory where the Quanta model scanning electron microscope is located, allowing for the quantification of stomatal density.

Finally, the yield and cost of each plot were projected per hectare to determine the commercial yield and production cost. Then, the commercial yield was multiplied by the unit price in kilograms to obtain the total income. This value was subtracted from the production cost to obtain the profit. Next, this result was divided by the production cost to obtain the profitability. This procedure was carried out for all treatments.

Profitability Formula 12.

$$\text{P.} = \frac{U}{C.p.} * 100 \quad (12)$$

where: P.: Profitability; U: Utility; C.p.: Cost of production.

3. Results

3.1. Soil analysis of the experimental area

After analyzing the soil in the INIA-Huaral laboratory, it was determined that the pH indicates it is moderately alkaline, that the levels of organic matter and phosphorus are low, and that the levels of nitrogen and potassium are within the medium ranges (Prialé, 2016). The calcium carbonate content is within normal values (Sales-Dávila et al., 2024). Regarding the levels of calcium, magnesium, sodium, and potassium, these are within normal values (McKean, 1993; see Table 2; INIA, 2025a). Therefore, this land is suitable for carrot cultivation, although it is necessary to incorporate fertilizer and properly prepare the land to optimize its properties.

For the nutritional recommendation of carrot cultivation, the soil was analyzed, which determined that 160 kg ha^{-1} of nitrogen, 80 kg ha^{-1} of phosphorus, and 60 kg ha^{-1} of potassium are needed (see Table 4) (INIA, 2025b). To provide these nutrients, BECB was applied, which increased the availability of these elements in the soil, promoting their absorption by the plant and improving its yield. For this purpose, the standard dose was set taking into account the amount of nitrogen.

3.2. Chemical analysis of BEBC

Regarding the chemical analysis of the BEBC, it was determined that the concentration of phosphorus and potassium was at low levels. However, the low C/N ratio indicates that the compost is mature (see Table 5) (INIA, 2025c). In comparison with another study, Vélez Chang (2024) analyzed this fertilizer and reported the values of organic matter (52.4%), nitrogen (1.2%), P_2O_5 (0.96%), K_2O (1.18%), and C/N ratio (37.99%). Likewise, Román et al. (2013) establish that the appropriate ranges for mature compost between 3 and 6 months should consider a C/N ratio between 10:1 and 15:1 and moisture between 30% and 40%. Therefore, when comparing the results, it is noted that this fertilizer has a higher nitrogen percentage and is suitable as a nutritional source, which benefits carrot cultivation.

Regarding the analysis of micronutrients in BEBC detailed in Table 9 (INIA, 2025d), a low concentration of iron, zinc, copper, and manganese is observed compared to other fertilizers. According to Marcelo Ângulo et al. (2022), the compost made with 33% blanching soil waste, 33% guinea pig manure, and 33% straw for four months showed concentrations of iron (5,666.5 ppm), zinc (51.85 ppm), copper (3.89 ppm), and manganese (138.05 ppm), and its application in radish cultivation improved the yield. Therefore, it is evident that this fertilizer is a nutritional source that improves carrot crop yield.

3.3. Physical characteristics of the carrot

After obtaining the data on the physical characteristics of the carrot, they were processed using analysis of variance, which determined that there was no significance, meaning there was no effect of the BEBC dose. The Duncan test determined that all treatments were classified with the same letter (a), indicating that there are no statistical differences and that T5 obtained the best results in all evaluations. The yield was 42.264 t ha^{-1}, 24.58% more than in T1, which was 31.875 t ha^{-1} (see Table 10 and Figure 1). These results are interpreted as indicating that a higher dose of BEBC improved nutrition and resilience against nutritional, environmental, and pest stress, resulting in higher yield.

3.4. Nutrient concentration in carrot leaves

Regarding the nutrient analysis in carrot leaves, it was determined that T_3 stood out for its concentration of nitrogen, potassium, phosphorus, sulfur, and chlorides, although it did not influence the yield. However, T_5, with sulfur, iron, and sodium, influenced the highest carrot yield (see Table 11) (AGQ Perú S.A.C., 2025). This result is interpreted as indicating that, with a higher dose of BEBC, the concentration of nutrients in the leaves decreased, which was associated with a significant increase in

Table 9. Micronutrient analysis of BEBC.

Elements	Iron	Zinc	Copper	Manganese
Amount (mg kg^{-1})	210.37	2.52	3.45	2.81

Source: INIA (2025d).

Table 10. Physical characteristics of the carrot by treatment.

Treatment	Dose of BEBC (kg ha^{-1})	Total plant length (cm)	Storage root size (cm)	Storage root diameter (cm)	Weight of a storage root (g)	Commercial yield of carrot (t ha^{-1})
T_5	4.8	48.763 a	16.746 a	5.025 a	238.33 a	42.264 a
T_4	4.2	48.516 a	16.254 a	4.904 a	228.33 a	40.965 a
T_3	3.6	47.960 a	16.054 a	4.854 a	211.67 a	38.410 a
T_2	3	47.533 a	15.833 a	4.700 a	193.33 a	35.376 a
T_1	0	47.400 a	14.700 a	4.660 a	180.00 a	31.875 a
Significance		N.S.	N.S.	N.S.	N.S.	N.S.
Coefficient of variation (%)		3.04	7.80	6.26	21.56	13.90

Note: Significance (S) and not significant (N.S.). It is mentioned that the same letters, according to Duncan's ranking, indicate that the treatments are statistically homogeneous.

Figure 1. Comparison of carrot development based on BEBC doses.

Table 11. Nutrient concentration in carrot leaves by treatment.

Elements	T_1	T_2	T_3	T_4	T_5	Normal range according to AGQ Peru S.A.C. (2025)
Macronutrients (%)						
Total Nitrogen	2.7	3.1	3.1	2.8	2.7	2.10 - 3.5
Potassium	2.14	2.19	2.76	1.89	1.79	2.80 - 4.0
Phosphorus	0.25	0.28	0.32	0.29	0.25	0.20 – 0.50
Calcium	3.45	3.58	3.34	3.37	3.52	1.40 – 3.00
Magnesium	0.24	0.29	0.28	0.23	0.21	0.30 - 0.50
Sulfur	0.95	0.99	1.17	1.12	1.17	
Micronutrients (mg kg^{-1})						
Iron	779	656	577	697	808	50 - 300
Manganese	246	128	74.0	85.8	98.9	60 - 200
Copper	14.7	11.5	10.4	9.86	10.9	5.00 – 15.00
Zinc	38.1	29.3	22.5	22.7	24.5	25.0 - 250
Boron	59.7	64.7	58.8	63.5	62.5	30.0 -100.0
Molybdenum	5.28	4.56	4.09	3.88	4.59	
Phytotoxic elements (%)						
Chlorides	< 0.025	0.032	0.046	< 0.025	< 0.025	
Sodium	1.310	1.142	1.499	1.341	1.538	

Source: AGQ Peru S.A.C. (2025).

antioxidant capacity and strengthened the plant against stress, resulting in higher yield.

3.5. Total nitrogen consumption in relation to antioxidant capacity

Regarding the total nitrogen consumption, T5 stood out with 183.4 kg ha^{-1}, 73.28% more than T1, which had 49 kg ha^{-1}. This influenced the considerable increase in antioxidant capacity, which reached 2,907.5 µmol Trolox/100 g. This increase resulted in a higher yield of 42.264 t ha^{-1} of carrots (see Table 6). This result is interpreted as a higher nitrogen consumption being associated with a considerable increase in antioxidant capacity, which resulted in a higher yield of the crop.

3.6. Total phosphorus consumption in relation to antioxidant capacity

Regarding the total phosphorus consumption, the highest dose (T5) stood out with 52.21 kg ha^{-1} of P_2O_5, which represents a 47.80% increase compared to T1, with 27.25 kg ha^{-1} of P_2O_5. This amount of diphosphorus pentoxide significantly increased the antioxidant capacity, reaching 2,907.5 µmol Trolox 100 g, resulting in a higher yield of 42.264 t ha^{-1} of carrots (see Table 7). This result is interpreted as indicating that, with a higher dose of BEBC (T5), there was greater consumption of phosphorus pentoxide, which was associated with a considerable increase in antioxidant capacity and, therefore, with a higher yield.

3.7. Total potassium consumption in relation to antioxidant capacity

In the total potassium consumption, T5 stood out with 822.74 kg ha^{-1} of K_2O, which represents a 1.16% difference compared to T1, with 813.14 kg ha^{-1} of K_2O. This higher potassium contribution was associated with a considerable increase in antioxidant capacity, reaching 2,907.5 µmol Trolox 100 g, which resulted in a higher yield of 42.264 t ha^{-1} of carrot (see Table 8). This result is interpreted as the higher dose of BECB favored adequate antioxidant capacity, which responded with higher crop yield.

3.8. Antioxidant capacity in carrot leaves

Regarding the evaluation of the antioxidant capacity of carrot leaves, as shown in Table 12 (IIN, 2025), it is observed that T_3 stood out with 3,521.8 µmol Trolox/100 g, which represents a 32.73% difference compared to T_1, which presented 2,368.9 µmol Trolox/100 g. However, this difference did not affect the yield. This result is interpreted as follows: at higher doses of BEBC (T_5), the antioxidant capacity decreased until an adequate concentration of this compound balanced the ROS, resulting in higher performance.

3.9. Stomatal density in relation to antioxidant capacity

Regarding the stomatal density related to the antioxidant capacity shown in Table 13, it is observed that T1 stood out with 245 stomata mm^{-2}; however, this amount did not influence the increase in antioxidant capacity or carrot yield, since T5 stood out for its higher yield (see Table 13 and Figure 2). This result is interpreted in the sense that with a higher dose of BECB (T_5), a lower stomatal density was obtained, which was associated with an adequate antioxidant capacity that balanced the ROS, resulting in a higher yield.

3.10. Profitability per treatment

Regarding the profitability of carrots, as shown in Table 14, the highest dose of BECB (T5) achieved the highest

Table 12. Total antioxidant capacity in lettuce leaves by treatment.

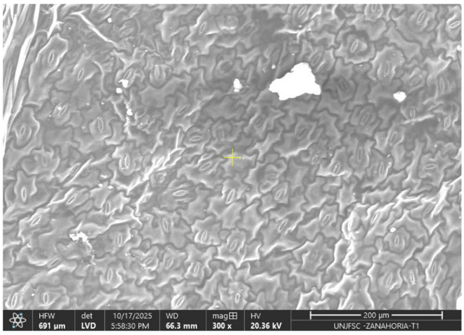
Treatment	Dose of BEBC (kg ha^{-1})	Result (µMol trolox /100 g of sample)	Commercial yield (t ha^{-1})
T_1	0	2,368.9	31.875
T_2	3	3,349.4	35.376
T_3	3.6	3,521.8	38.410
T_4	4.2	2,706.8	40.965
T_5	4.8	2,907.5	42.264

Source: IIN (2025).

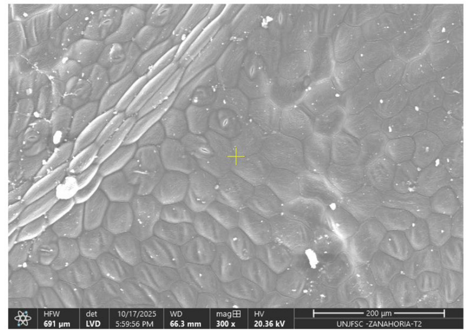
Table 13. Stomatal density in relation to antioxidant capacity.

Evaluation parameters	Treatment				
	T_1	T_2	T_3	T_4	T_5
Number of stomata per 0.3190 mm^2	78	67	50	41	35
Stomatal density (number of stomata mm^{-2})	244.5	210.0	156.7	128.5	109.7
Antioxidant capacity (µMol trolox 100 g)	2,368.9	3,349.4	3,521.8	2,706.8	2,907.5
Commercial yield (t ha^{-1})	31.875	35.376	38.410	40.965	42.264

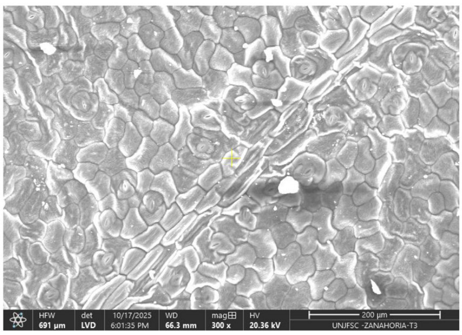
Note: Projected area of the micrograph is equivalent to 0.3190 mm^2.



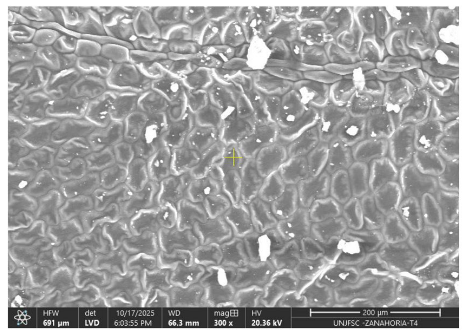
T_1 = 245 stomata mm^{-2}



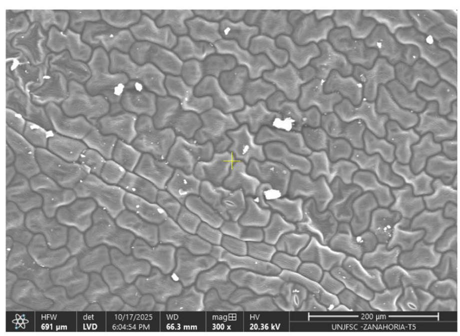
T_2 = 210 stomata mm^{-2}



T_3 = 157 stomata mm^{-2}



T_4 = 129 stomata mm^{-2}



T_5 = 110 stomata mm^{-2}

Figure 2. Micrograph of carrot stomata by treatment.

profitability, with 139.8%, which is 21.53% higher than T1, with 109.7%, resulting in higher income. This result is interpreted as the highest fertilizer dose generating more than double the income and exceeding the T1 dose by more than one-fifth, indicating that the T5 dose is profitable and an economical alternative, which can serve as a recommendation for farmers in the Végueta district.

4. Discussion

4.1. Physical characteristics of the carrot

When statistically analyzing the data on the physical characteristics of the carrot, it was determined that there were no statistical differences in the treatments. Additionally, it is noted that T5 achieved the best results in all evaluations and in yield, with 24.58% more than T1 (see Table 10). This result is analyzed as indicating that, by using a higher dose of BEBC, beneficial elements and microorganisms were added to the soil, which improved their availability for plant absorption. The above aligns with Kumar et al. (2022), who highlight that microorganisms (plant growth-promoting rhizobacteria, phosphate-solubilizing bacteria, among others) perform activities that promote growth due to their beneficial characteristics and their key role in improving access to nitrogen, phosphorus, potassium, zinc, and sulfur. They also optimize biochemical reactions, such as transpiration, photosynthesis, and the formation and translocation of carbohydrates to the storage root, and increase antioxidant capacity. In fact, Gavelienė et al. (2021) demonstrated in their trials that the

Table 14. Profitability of carrots by treatment.

Treatment	Dose of BEBC (kg ha^{-1})	Commercial yield (kg ha^{-1})	Unit value per kg ($)	Total income ($)	Cost of production ($)	Utility ($)	Profitability (%)
T_1	0	31,875	0.298	9,498.8	4,529.98	4,968.8	109.7
T_2	3	35,376	0.298	10,542.0	4,980.87	5,561.2	111.7
T_3	3.6	38,410	0.298	11,446.2	5,071.05	6,375.1	125.7
T_4	4.2	40,965	0.298	12,207.6	5,161.23	7,046.3	136.5
T_5	4.8	42,264	0.298	12,594.7	5,251.40	7,343.3	139.8

Note: Price of dollar is S/. 3.36 soles.

combination of microbial biostimulants (*Bacillus subtilis*, *Lactobacillus* spp., *Rhodopseudomonas* spp., and genera associated with nitrogen fixation and biocontrol such as Azotobacter, Rhizobium, Bradyrhizobium, and Trichoderma) increased the antioxidant activity of carrots by 10% to 20% compared to untreated carrots. Overall, these biochemical mechanisms resulted in higher crop yields, which aligns with the findings of Pellegrini et al. (2021), who state that strains of plant growth-promoting bacteria (*Azospirillum brasilense*, *Gluconacetobacter diazotrophicus*, *Herbaspirillum seropedicae*, and *Burkholderia ambifaria*) benefit the growth and development of carrots, as evidenced in field trials.

4.2. Concentration of nutrients in leaves

When analyzing the nutrients present in carrot leaves, it was determined that T3 stood out in most elements. However, T5, which contains sulfur, iron, and sodium, influenced the highest yield (see Table 11) (AGQ Perú S.A.C., 2025). This result indicates that the higher concentration of sulfur is involved in the synthesis of amino acids and the formation of antioxidant compounds, while the concentration of iron contributes to the formation of enzymatic cofactors and the biosynthesis of chlorophyll. Likewise, sodium can partially replace potassium in osmotic regulation and contribute to the energy balance of plant cells. Consequently, these elements participated in biochemical reactions that increased the antioxidant capacity, resulting in higher yield. The above is supported by Li et al. (2020), who mention that sulfur is essential for plant development, as it is absorbed from the soil in the form of sulfate and translocated to the leaf plastids, where it is assimilated as cysteine, which acts as a precursor of metabolites with biological and antioxidant functions such as glutathione and methionine. For their part, Murgia et al. (2022) point out that iron is an essential micronutrient for plants, as many cellular processes, such as photosynthesis, respiration, and ROS uptake, depend on adequate levels of this element. Finally, Nieves-Cordones et al. (2016) state that, although sodium is not essential for most plants, with the exception of halophytes, it is compartmentalized outside the cytoplasm and can accumulate in high concentrations in the vacuoles, where it performs an osmotic function, proving beneficial by partially substituting potassium.

4.3. Total nitrogen consumption in relation to antioxidant capacity

Regarding the total nitrogen consumption, T5 stood out with 183.4 kg ha^{-1}, 73.28% more than T1, which was 49 kg ha^{-1}. This increase was associated with a considerable rise in antioxidant capacity, which resulted in higher yield (see Table 6). This result is analyzed in the sense that a higher dose of BEBC (T5) provided a greater amount of this element and beneficial microorganisms that improved its availability for the plant to absorb under moderately alkaline soil conditions. This optimized biochemical reactions and led to greater formation and translocation of carbohydrates toward the storage root, as well as a significant increase in antioxidant capacity. All these processes strengthened the plant against stress, resulting in a higher carrot yield. This result is consistent with that of Loh et al. (2013), who demonstrated that spent bleaching earth, composted with agricultural and palm oil by-products, enhances the physical attributes of the soil for plant growth and microbial rejuvenation, due to the adequate amount of improved organic carbon, cation exchange capacity, water retention capacity, and the C:N. Likewise, Zayed et al. (2023) highlight that nitrogen is an essential element that is part of many compounds, such as amino acids, the construction of enzymes and proteins, as well as chlorophyll, which is fundamental in photosynthesis and improves the quality of leaves to absorb solar energy, resulting in higher plant yield. Finally, Wang et al. (2023) found that nitrogen application improved the activities of enzymatic antioxidants (SOD, CAT, and GR) and non-enzymatic antioxidants such as ascorbic acid (AsA), which eliminated the excess ROS produced by salt stress, resulting in enhanced osmotic substances (soluble protein, soluble sugar, and proline) in the seedlings.

4.4. Total phosphorus consumption in relation to antioxidant capacity

In phosphorus consumption, the T5 dose with 52.21 kg ha^{-1} of P_2O_5 stood out, representing 47.8% more than T1. This amount was associated with an increase in antioxidant capacity and higher carrot yield (see Table 7). This result indicates that the highest dose of BECB provided a greater amount of phosphorus and microorganisms, which increased its availability for absorption. Consequently, this contribution optimized energy formation, transpiration, photosynthesis, carbohydrate biosynthesis, and translocation to the root, as well as other processes such as antioxidant capacity, resulting in higher yield. In this regard, Bohórquez-Sandoval et al. (2024) argue that a source of phosphorus and microorganisms is compost, which, when applied to the soil, improves availability and recycling through symbiotic relationships, microbial interactions, and the action of phosphorus genes, making it sustainable in agriculture. Likewise, Riaz et al. (2023) point out that soil phosphorus is classified into organic and inorganic forms and that plants absorb it directly through the epidermis and root hairs or through association with arbuscular mycorrhizal fungi. For their part, Odoom and Ofosu (2024) highlight that phosphorus is involved in the formation of adenosine triphosphate, reduced nicotinamide adenine dinucleotide phosphate, and sugar phosphates, which are indispensable for the fixation, reduction, and regeneration of carbon in the ribulose-1,5-bisphosphate cycle; moreover, it is involved in the regulation of ribulose-1,5-bisphosphate carboxylase/oxygenase activase. In summary, phosphorus acts as a central axis in photosynthesis, carbohydrate synthesis, and antioxidant capacity, which strengthens and maximizes performance.

4.5. Total potassium intake in relation to antioxidant capacity

In the total consumption of K_2O, T5 stood out with 822.74 kg ha^{-1}, which represents a 1.16% difference compared to T1. This greater availability of potassium was associated with an increase in antioxidant capacity, which resulted in a higher carrot yield (see Table 8). This result is analyzed in the sense that the highest dose of BEBC provided more K_2O, which improved its availability and absorption. This amount of the nutrient optimized transpiration, photosynthesis, protein synthesis, the transport of carbohydrates from the leaves to the root, and other processes such as antioxidant capacity, and also regulated water and reduced oxidative stress. Consequently, this element strengthened the plant and facilitated the accumulation of sugars in the root, resulting in higher yield and quality. In this regard, Vélez Chang et al. (2022) mention that the BEBC provided 0.78% K_2O, which, at its highest dose (T5), of 10 t ha^{-1}, is equivalent to 78 kg ha^{-1} of K_2O, an amount that corresponded to the higher yield of the beet. For their part, Al-Dulaimy and Al-Abdaly (2024) highlight that potassium promotes the physiological process of carrots through its function as the transport of sugars and carbohydrates from the leaves to the storage roots, which stimulates root growth, strengthens against pests, and contributes to resistance to drought and frost stress. Finally, Sardans and Peñuelas (2021) state that potassium positively regulates antioxidant metabolism and strengthens growth under water and osmotic stress.

4.6. Antioxidant capacity in carrot leaves

The antioxidant capacity of the leaves stands out in T3 with 3,521.8 µmol Trolox/100 g, 32.73% more than T1 with 2,368.9 µmol Trolox/100 g. However, the highest dose of BEBC (T5), with an adequate antioxidant capacity (37,264 µmol Trolox/100 g), influenced the higher yield of the carrot (see Table 12) (IIN, 2025). Consequently, transpiration, carbohydrate synthesis, translocation to the storage root reserve, antioxidant capacity, and other biochemical processes were optimized. Overall, these biochemical processes acted as a defense by balancing ROS, which strengthened against environmental, nutritional, and pest stress, resulting in higher crop yield. In this regard, Kiraci (2018) determined that doses of poultry manure stood out in the diameter, root length, weight, total soluble solids and sugar content, and antioxidant activity of carrots. Complementarily, Anli et al. (2020) state that the association of arbuscular mycorrhizal fungi/plant growth-promoting rhizobacteria-compost increased photosynthetic pigments and stomatal conductance mediated by abscisic acid, which enhanced CO_2 and photosynthetic capacity; moreover, it favored the accumulation of osmolytes, the activation of metabolites, and antioxidant activity, thus contributing to the osmotic adjustment of leaves, the elimination of ROS, and the reduction of stress. Miyamoto et al. (2023) state that compost increased the bacterial composition of the soil, improving the productivity, antioxidant activity, color, and flavor of the carrot, as well as the levels of characteristic leaf and root metabolites.

4.7. Stomatal density in relation to antioxidant capacity

Regarding stomatal density, it is noted that T1 stood out with 245 stomata mm^{-2}; however, this amount did not influence the increase in antioxidant capacity or carrot yield, since a lower number of stomata (T5), with 110 stomata mm^{-2}, stood out for its higher yield (see Table 13). This result shows that with a higher dose of BEBC, nutrients were added to the soil, improving their availability for greater absorption by the plant. This was associated with a reduction in stomatal density and an adequate antioxidant capacity that balanced ROS and optimized transpiration, photosynthesis, and the formation and translocation of carbohydrates. Consequently, these processes contributed to the thickening of the storage root and to the tolerance to nutritional, environmental, and pest stress, leading to higher yield and quality of the crop. The aforementioned is supported by Legua Cárdenas et al. (2024), who highlighted that T5, which is the high dose of sugarcane compost, achieved the lowest stomatal density (369 stomata mm^{-2}) in cabbage leaves and was associated with the absorption of potassium, phosphorus, calcium, and boron, resulting in increased yield. Likewise, Álvarez-Holguín et al. (2018) highlighted that in banderita grass, genotypes with lower stomatal density and index but with a larger stomatal area can produce a greater amount of biomass and, by exhibiting a higher chlorophyll concentration, tend to be more productive. Finally, Cruz Nieto et al. (2025c) found that T5 with adequate antioxidant capacity (4,212.8 µmol Trolox/100 g) in cilantro leaves showed efficient nutrient absorption, lower stomatal density, and optimized physiological reactions that strengthened the plant against stress and achieved higher yields.

4.8. Profitability per treatment

Regarding profitability, the highest dose of BECB (T5) stood out, with 139.8%, which exceeded T1 by 21.53%, with 109.7%, generating higher income (see Table 14). This result indicates that more than double the investment was obtained with the highest dose and more than one-fifth in relation to the T1 dose. Consequently, the application of this fertilization measure generated a greater economic gain in carrot cultivation, which is beneficial. These results suggest that it is advisable for farmers in the Chilampa populated center area, in the Végueta district.

5. Conclusion

It was concluded that T3 stands out with 3,521.8 µmol of Trolox/100 g, which is more than 32.73% higher than T1. However, this amount did not affect the yield. An adequate antioxidant capacity, such as that of T5, with 2907.5 µmol Trolox/100 g, influenced the higher yield of the carrot. Therefore, with a higher dose of BEBC, nutrients were added to the soil that improved their availability for absorption by the plant, which favored physiological processes such as transpiration, photosynthesis, carbohydrate formation, and translocation, and contributed to the balance of ROS. As a result, plants were strengthened against nutritional, environmental, and pest stress, and consequently, a higher yield was achieved.

It was also determined that, in the concentration of nutrients in the leaves, T3 with nitrogen, potassium, phosphorus, sulfur, and chlorides stood out; however, this did not influence the yield. In contrast, T5 with sulfur, iron, and sodium, along with adequate antioxidant capacity, contributed to the higher carrot yield. Therefore, the combination of these nutrients and the increase in antioxidants favored the processes of transpiration, photosynthesis, biomass formation, and carbohydrate translocation to the storage root and balanced the ROS, resulting in plants strengthened against stress and, consequently, in higher yield.

Finally, it was determined that the stomatal density was highest in T1, with 245 stomata mm^{-2}, but it did not influence the higher yield. In contrast, T5, with 110 stomata mm^{-2} and an adequate antioxidant capacity, achieved a higher carrot yield. Therefore, this lower number of stomata was taken as an indicator and, along with an increase in antioxidants, favored the physiological processes of transpiration, carbohydrate formation, and translocation to the root storage reserve, and contributed to the balance of ROS. Consequently, they strengthened the plants against stress and a higher yield was obtained.

Data Availability Statement

I mention to you that the entire data set supporting the results of this study was published in the article itself.

References

ABDELBASIR, S.M., SHEHAB, A.I. and ABDEL KHALEK, M.A., 2023. Spent bleaching earth; recycling and utilization techniques: a review. *Resources, Conservation & Recycling Advances*, vol. 17, pp. 200124. https://doi.org/10.1016/j.rcradv.2022.200124.

AGQ PERÚ S.A.C., 2025. *Informe de ensayo-material vegetal: acreditado IAS, testing laboratory TL-502: códigos V-25/067015, V-25/067016, V-25/067017, V-25/067018, V-25/067019*. Lima: AGQ LABS.

AIT-EL-MOKHTAR, M., BASLAM, M., BEN-LAOUANE, R., ANLI, M., BOUTASKNIT, A., MITSUI, T., WAHBI, S. and MEDDICH, A., 2020. Alleviation of detrimental effects of salt stress on date palm (*Phoenix dactylifera* L.) by the application of arbuscular mycorrhizal fungi and/or compost. *Frontiers in Sustainable Food Systems*, vol. 4, pp. 131. https://doi.org/10.3389/fsufs.2020.00131.

AL-DULAIMY, O.A.S. and AL-ABDALY, M.M., 2024. The effect of organic and potassium fertilization on the chemical content and quality of fruits in carrots. *Pakistan Journal of Life and Social Sciences*, vol. 22, no. 1, pp. 3589-3596. https://doi.org/10.57239/PJLSS-2024-22.1.00261.

ALMAGRO, L., CORREA-SABATER, J.M., SABATER-JARA, A.B. and PEDREÑO, A.M., 2022. Biotechnological production of β-carotene using plant in vitro cultures. *Planta*, vol. 256, no. 2, pp. 41. https://doi.org/10.1007/s00425-022-03953-9. PMid:35834131.

ALMANZA GÁMEZ, R., JIMÉNEZ PEREA, M.G., MARES MONCADA, M., MEJÍA CÁRDENAS, G.E., OLVERA HERNÁNDEZ, A.G., RÍOS FUENTES, B. and LÓPEZ GONZÁLEZ, M.D.L.L., 2024. Caracterización de la producción de hidromiel artesanal y análisis de sus propiedades antioxidantes. *Jóvenes en la Ciencia*, vol. 28, pp. 1-13. https://doi.org/10.15174/jc.2024.4570.

ÁLVAREZ-HOLGUÍN, A., MORALES-NIETO, C.R., CORRALES-LERMA, R., AVENDAÑO-ARRAZATE, C.H., RUBIO-ARIAS, H.O. and VILLARREAL-GUERRERO, F., 2018. Stomatal characterization, chlorophyll concentration and their relation with biomass production of *Bouteloua curtipendula. Agronomía Mesoamericana*, vol. 29, no. 2, pp. 251-261. https://doi.org/10.15517/ma.v29i2.29900.

ANLI, M., BASLAM, M., TAHIRI, A., RAKLAMI, A., SYMANCZIK, S., BOUTASKNIT, A., AIT-EL-MOKHTAR, M., BEN-LAOUANE, R., TOUBALI, S., AIT RAHOU, Y., AIT CHITT, M., OUFDOU, K., MITSUI, T., HAFIDI, M. and MEDDICH, A., 2020. Biofertilizers as strategies to improve photosynthetic apparatus, growth, and drought stress tolerance in the date palm. *Frontiers in Plant Science*, vol. 11, pp. 516818. https://doi.org/10.3389/fpls.2020.516818. PMid:33193464.

BELLO, M.A. and PINO, M.T., 2000 [viewed 4 February 2026]. *Cálculo básicos para fertirrigar* [online]. Santiago: INIA, 31 p. Boletín, no. 26. Available from: https://biblioteca.inia.cl/server/api/core/bitstreams/0f253cee-c90d-464c-ab04-d60ce2cab9ab/content

BOHÓRQUEZ-SANDOVAL, L.J., GARCÍA-MOLANO, J.F., PASCUAL-VALERO, J.A. and ROS-MUÑOZ, M., 2024. A comprehensive review on organic waste compost as an effective phosphorus source for sustainable agriculture. *International Journal of Recycling of Organic Waste in Agriculture*, vol. 13, no. 4, pp. 1-16. https://doi.org/10.57647/ijrowa-ybbx-kp03.

CARBAJAL, S., 2022. *Biosorción con el bagazo de la caña de azúcar y hongo Penicillium janthinellum para la recuperación de la arcilla residual generado en el proceso de blanqueo del aceite comestible*. Callao: Universidad Nacional del Callao, 112 p. Tesis para Optar el Título Profesional de Ingeniero Ambiental y de Recursos Naturales.

CARRASCO, J. and AGUIRRE, C., 2023 [viewed 4 February 2026]. *Cálculo de fertilización con fósforo a partir del análisis de fertilidad de suelos* [online]. Santiago: INIA. Available from: https://biblioteca.inia.cl/server/api/core/bitstreams/7935f241-774a-4cad-9279-279e82d55f0e/content

CHEONG, K.Y., LOH, S.K. and SALIMON, J., 2013. Effect of spent bleaching earth based bio organic fertilizer on growth, yield and quality of eggplants under field condition. *AIP Conference Proceedings*, vol. 1571, pp. 744-748. https://doi.org/10.1063/1.4858743.

CRUZ NIETO, D.D., MUGURUZA CRISPIN, N.E., CAIRA MAMANI, C.M., CASTRO BARTOLOMÉ, H.J., INGA SOTELO, M.A., ALBERTO, M.N.M., VALDERRAMA ROMERO, A.S., VARGAS GODOY, V.C., MORE LÓPEZ, J.M., CHANDUCAS TANTALEÁN, H.E., MENACHO JAVIER, N.E., LARA CASTILLO, M.A., FLORES CASANOVA, W., BENAVENTE RAMÍREZ, E.R., APOLÍN MONTES, L.A. and DIESTRA SALINAS, F., 2024a. Biological and chemical characterization in relation to the yield of radish (*Raphanus sativus* L.) nourished with humus from plant residues. *Brazilian Journal of Biology*, vol. 84, e281235. https://doi.org/10.1590/1519-6984.283287. PMid:38656077.

CRUZ NIETO, D.D., MUGURUZA CRISPÍN, N.E., CASTAÑEDA CHIRRE, E.T., ROMERO MENACHO, J.U., MARTINEZ LOLI, M.I., ALVAREZ QUINTEROS, C.P., CABANILLAS SULCA, J.C., OSSO ARRIZ, O.O., LUPERDI RIOS, F.V., QUISPE BARRANTES, P.M., BAUTISTA ESPINOZA, M.V., REAÑO RIVERA, J.R., PESANTES ARRIOLA, G.C., CAIRA MAMANI, C.M., MORALES ALBERTO, M.N. and CHICLLA SALAZAR, A., 2025b. Anthocyanins in relation to nutrients, stomatal density, and yield of purple lettuce (*Lactuca sativa* L.) fertilized with compost based on bleaching earth. *Brazilian Journal of Biology*, vol. 85, e291967. https://doi.org/10.1590/1519-6984.291967. PMid:40531724.

CRUZ NIETO, D.D., MUGURUZA CRISPÍN, N.E., ROMERO MENACHO, J.U., OSSO ARRIZ, O.O., MAMANI SALCEDO, B.L., LUPERDI RIOS, F.V., ALVAREZ QUINTEROS, C.P., NICHO VARGAS, J.O., MARTINEZ LOLI, M.I., DEXTRE MENDOZA, R.W., MORALES ALBERTO, M.N., CAIRA MAMANI, C.M., AGUILAR ANCCOTA, R., LACHERRE RODRIGUEZ, G.P., RAMOS VERA, J.R., BAUTISTA ESPINOZA, M.V., PESANTES ARRIOLA, G.C. and REAÑO RIVERA, J.R., 2025c. Antioxidant related to nutrition, stomatal density, and yield in cilantro *(Coriandrum sativum* L.) nourished with leachate from compost based on vegetable waste. *Brazilian Journal of Biology*, vol. 85, e293174. https://doi.org/10.1590/1519-6984.293174. PMid:40802391.

DORANTES-SALAZAR, E.L., BÁEZ-GONZÁLEZ, J.G., GASTELÚM-MARTÍNEZ, É., MORALES-LANDA, J.L. and GARCÍA-MARQUEZ, E., 2023. Determinación de actividad antioxidante en alimentos funcionales. *Investigación y Desarrollo en Ciencia y Tecnología de Alimentos*, vol. 8, no. 1, pp. 643-649. https://doi.org/10.29105/idcyta.v8i1.84.

EUROPEAN PALM OIL ALLIANCE – EPOA, 2016 [viewed 10 January 2026]. *Es el aceite vegetal más utilizado del mundo. ¿Qué es el aceite de palma?* [online]. Madrid: Fundación Española del Aceite de Palma Sostenible. Boletín Informativo. Available from: https://aceitedepalmasostenible.es/

GAVELIENĖ, V., ŠOCIK, B., JANKOVSKA-BORTKEVIČ, E. and JURKONIENĖ, S., 2021. Plant microbial biostimulants as a promising tool to enhance the productivity and quality of carrot root crops. *Microorganisms*, vol. 9, no. 9, pp. 1850. https://doi.org/10.3390/microorganisms9091850. PMid:34576744.

GUTIÉRREZ RODAS, M., 2022 [viewed 4 February 2026]. Efecto de la actividad antioxidante en una conserva de arándanos. *Polo del Conocimiento: Revista Científico-Profesional* [online], vol. 7, no. 11, pp. 1243-1263. Available from: https://www.polodelconocimiento.com/ojs/index.php/es/article/view/4920/11914

HERNÁNDEZ MENDOZA, S. and DUANA AVILA, D., 2020. Técnicas e instrumentos de recolección de datos. *Boletín Científico de las Ciencias Económico Administrativas del ICEA*, vol. 9, no. 17, pp. 51-53. https://doi.org/10.29057/icea.v9i17.6019.

HERNÁNDEZ, J. and ISTURIZ, J., 2022. Alternativas de recuperación, reúso, reciclaje y disposición final de la tierra de blanqueo gastadas en el proceso de refinación del aceite vegetal. *Agroindustria, Sociedad y Ambiente*, vol. 1, no. 18, pp. 4-23. https://doi.org/10.5281/zenodo.6478821.

HIRZEL, J. and SALAZAR, F., 2016 [viewed 1 February 2026]. *Guía de manejo y buenas prácticas de aplicación de enmiendas orgánicas en agricultura* [online]. Chile: INIA, Ministerio de Agricultura. Boletín INIA, no. 325. Available from: https://biblioteca.inia.cl/server/api/core/bitstreams/ca61659e-998f-489e-8bf6-e771298d6f09/content

INSTITUTO DE INVESTIGACIÓN NUTRICIONAL – IIN, 2025. *Resultados de laboratorio de fisicoquímica: capacidad antioxidante de la zanahoria, no. 000217 – 2025.* La Molina: IIN, Laboratorio de Análisis de Alimentos.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2025a. *Análisis de suelo: informe de análisis de suelo, no. 091534-25/SU/DO/LABSAF DONOSO.* Perú: INIA.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2025b. *Recomendación de macronutrientes para zanahoria: resultados nutricionales no. SU-091534*. Perú: INIA.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2025c. *Informe del compost a base de tierra de blanqueo: resultados de característica química: INIA no. 100035-25NA/AB/DO/LABSAF – DONOSO.* Perú: INIA.

IPANAQUÉ, J., 2023. *Fertilización con compost producido de residuos sólidos orgánicos del mercado para mayor rendimiento en cultivo de vainita (Phaseolus vulgaris L.), Huaura – 2022*. Huacho: Universidad Nacional José Faustino Sánchez Carrión, 69 p. Tesis de Doctor en Ciencias Ambientales.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2025d. *Análisis de micro elementos compost a base de tierra de blanqueo. Resultados de micronutrientes: INIA no. 100035-25NA/AB/DO/LABSAF – DONOSO*. Perú: INIA.

KASS, C.L.D., 1998 [viewed 2 February 2026]. *Fertilidad de suelos* [online]. San José: EUNED. Available from: https://books.google.com.pe/books?id=sRua411JhvgC&pg=PP8&dq=KASS+FERTILIDAD+DE+SUELOS&hl=es&sa=X&ved=2ahUKEwiQ_p2Tx_r0AhU_qZUCHcNUAwQQ6AF6BAgHEAI#v=onepage&q=KASS%20FERTILIDAD%20DE%20SUELOS&f=false

KEOGH-BROWN, M.R., JENSEN, H.T., BASU, S., AEKPLAKORN, W., CUEVAS, S., DANGOUR, A.D., GHEEWALA, S.H., GREEN, R., JOY, E.M., ROJROONGWASINKUL, N., THAIPRASERT, N., SHANKAR, B. and SMITH, R.D., 2019. Evidence on the magnitude of the economic, health and population effects of palm cooking oil consumption: an integrated modelling approach with Thailand as a case study. *Population Health Metrics*, vol. 17, no. 1, pp. 12. https://doi.org/10.1186/s12963-019-0191-y. PMid:31420043.

KIRACI, S., 2018. Effects of seaweed and different farm manures on growth and yield of organic carrots. *Journal of Plant Nutrition*, vol. 41, no. 6, pp. 716-721. https://doi.org/10.1080/01904167.2018.1425435.

KUMAR, S., DIKSHA., SINDHU, S.S. and KUMAR, R., 2022. Biofertilizers: an ecofriendly technology for nutrient recycling and environmental sustainability. *Current Research in Microbial Sciences*, vol. 3, pp. 100094. https://doi.org/10.1016/j.crmicr.2021.100094. PMid:35024641.

LEGUA CÁRDENAS, J.A., CAMPOS DIAZ, A.H., FLORES BRICEÑO, R., SAUCEDO LÓPEZ, M.C., CARO SOTO, F.G. and VÉLEZ CHANG, D.J., 2024. Fertilización de la col *(Brassica oleracea* L.) en una aplicación de la agricultura orgánica utilizando compost. *Alfa Revista de Investigación en Ciencias Agronómicas y Veterinaria*, vol. 8, no. 23, pp. 508-519.

LI, Q., GAO, Y. and YANG, A., 2020. Sulfur homeostasis in plants. *International Journal of Molecular Sciences*, vol. 21, no. 23, pp. 8926. https://doi.org/10.3390/ijms21238926. PMid:33255536.

LOH, S.K., JAMES, S., NGATIMAN, M., CHEONG, K.Y., CHOO, Y.M. and LIM, W.S., 2013. Enhancement of palm oil refinery waste – Spent bleaching earth (SBE) into bio organic fertilizer and their effects on crop biomass growth. *Industrial Crops and Products*, vol. 49, pp. 775-781. https://doi.org/10.1016/j.indcrop.2013.06.016.

MARCELO ÂNGULO, N.M., SUSANIBAR RAMÍREZ, E.T., GARCÍA CORDERO, O. and LEGUA CÁRDENAS, J.A., 2022. Compostaje de los residuos industriales de tierra de blanqueo para su reciclado como productos fertilizantes. *Revista Alfa*, vol. 6, no. 17, pp. 239-246. https://doi.org/10.33996/revistaalfa.v6i17.164.

MCKEAN, S., 1993 [viewed 5 February 2026]. *Manual de análisis de suelos y tejido vegetal: una guía teórica y práctica de metodologías* [online]. Cali: Laboratorio de Servicios Analíticos, Centro Internacional de Agricultura Tropical. Documento de Trabajo, no. 129. Available from: https://drive.google.com/file/d/1CwfNJhMeY0JuUCwjPUkwceF8chg45wN9/view?usp=sharing

MEJÍA-REYES, J.D., GARCÍA-CABRERA, K.E., VELÁZQUEZ-OVALLE, G. and VÁZQUEZ-OVANDO, A., 2021. Antioxidant capacity: concepts, quantification methods and use for tropical fruits and derived products characterization. *Revista Colombiana de Investigaciones Agroindustriales*, vol. 9, no. 1, pp. 9-33. https://doi.org/10.23850/24220582.4023.

MISHRA, N., JIANG, C., CHEN, L., PAUL, A., CHATTERJEE, A. and SHEN, G., 2023. Achieving abiotic stress tolerance in plants through antioxidative defense mechanisms. *Frontiers in Plant Science*, vol. 14, pp. 1110622. https://doi.org/10.3389/fpls.2023.1110622. PMid:37332720.

MIYAMOTO, H., SHIGETA, K., SUDA, W., ICHIHASHI, Y., NIHEI, N., MATSUURA, M., TSUBO, A., TOMINAGA, N., AONO, M., SATO, M., TAGUCHI, S., NAKAGUMA, T., TSUJI, N., ISHII, C., MATSUSHITA, T., SHINDO, C., ITO, T., KATO, T., KUROTANI, A., SHIMA, H., MORIYA, S., WADA, S., HORIUCHI, S., SATOH, T., MORI, K., NISHIUCHI, T., MIYAMOTO, H., KODAMA, H., HATTORI, M., OHNO, H., KIKUCHI, J. and YOKOTA HIRAI, M., 2023. An agroecological structure model of compost—soil—plant interactions for sustainable organic farming. *ISME Communications*, vol. 3, no. 1, pp. 28. https://doi.org/10.1038/s43705-023-00233-9. PMid:37002405.

MODIBA, M.N., NKOANA, I. and SELELO, M.E., 2025. Population growth and its effects on natural resources in South Africa. *International Journal of Social and Educational Innovation*, vol. 12, no. 24, pp. 100-115. https://doi.org/10.5281/zenodo.17358810.

MURGIA, I., MARZORATI, F., VIGANI, G. and MORANDINI, P., 2022. Plant iron nutrition: the long road from soil to seeds. *Journal of Experimental Botany*, vol. 73, no. 6, pp. 1809-1824. https://doi.org/10.1093/jxb/erab531. PMid:34864996.

NIEVES-CORDONES, M., AL SHIBLAWI, F.R. and SENTENAC, H., 2016. Roles and transport of sodium and potassium in plants. In: A. SIGEL, H. SIGEL and R. SIGEL, eds. *The alkali metal ions: their role for life.* Cham: Springer, vol. 16. https://doi.org/10.1007/978-3-319-21756-7_9.

ODOOM, A. and OFOSU, W., 2024. Role of phosphorus in the photosynthetic dark phase biochemical pathways. In: *Phosphorus in soils and plants*. IntechOpen. https://doi.org/10.5772/intechopen.112573.

ORGANIZACIÓN DE LAS NACIONES UNIDAS PARA LA ALIMENTACIÓN Y LA AGRICULTURA – FAO, 2022. *El estado de la seguridad alimentaria y la nutrición en el mundo 2022: adaptación de las políticas alimentarias y agrícolas para hacer las dietas saludables más asequibles.* Rome. https://doi.org/10.4060/cc0639es.

PELLEGRINI, M., PAGNANI, G., ROSSI, M., D'EGIDIO, S., DEL GALLO, M. and FORNI, C., 2021. *Daucus carota* L. seed inoculation with a consortium of bacteria improves plant growth, soil fertility status and microbial community. *Applied Sciences*, vol. 11, no. 7, pp. 3274. https://doi.org/10.3390/app11073274.

PRASAD, R. and SHIVAY, Y.S., 2020. Agronomic biofortification of plant foods with minerals, vitamins and metabolites with chemical fertilizers and liming. *Journal of Plant Nutrition*, vol. 43, no. 10, pp. 1534-1554. https://doi.org/10.1080/01904167.2020.1738464.

PRIALÉ, C.A., 2016 [viewed 5 February 2026]. *Muestreo de suelos: referencias sobre el análisis e interpretación de resultados* [online]. Lima: INIA. Available from: https://repositorio.inia.gob.pe/server/api/core/bitstreams/e45a30c0-d2f5-4a41-872e-79425b3d752a/content

RIAZ, M., AZHAR, M.T., KAMRAN, M., AZIZ, O. and WANG, X., 2023. Role of arbuscular mycorrhizal fungi in plant phosphorus acquisition for sustainable agriculture. In: A. IQBAL, M. IQBAL, M. ALAMZEB, S. MEIZHEN, Z. XILING, M. ARIF, X. DU and E. LICHTFOUSEED, eds. *Phosphorus use efficiency for sustainable agriculture*. Cham: Springer, pp. 155-176. Sustainable Agriculture Reviews, no. 58. https://doi.org/10.1007/978-3-031-16155-1_8.

RODRÍGUEZ, C., 2013. *Niveles de ingreso familiar y los patrones de consumo agroalimentarios en el distrito de Tacna*. Tacna: Universidad Nacional Jorge Basadre Grohmann-Tacna, 95 p. Tesis para Optar al Título Profesional de Ingeniero en Economía Agraria.

ROMÁN, P., MARTÍNEZ, M.M. and PANTOJA, A., 2013 [viewed 5 February 2026]. *Manual de compostaje del agricultor experiencias en América Latina* [online]. Roma: FAO. Available from: https://www.fao.org/3/i3388s/I3388S.pdf

SALES-DÁVILA, B., SAMANIEGO-VIVANCO, T.D., DURAND-PASCO, K.A., NORABUENA-SEGOVIA, A.A., CALDERÓN-ESPINOZA, R.J., ORTEGA-VEGA, J.M., MUNAYCO- PERALTA, K.E., LAZO-TORREBLANCA, E.E., LAZO- TORREBLANCA, E.E., SANDOVAL ARTEAGA, I.S. and CALDERON PAREDES, L.E., 2024 [viewed 5 February 2026]. *Manual para el análisis de suelos agrícolas y agua para riego* [online]. Lima: INIA. Available from: https://repositorio.inia.gob.pe/items/579d9e8f-663e-47f9-828d-a816b511a50f

SARDANS, J. and PEÑUELAS, J., 2021. Potassium control of plant functions: ecological and agricultural implications. *Plants*, vol. 10, no. 2, pp. 419. https://doi.org/10.3390/plants10020419. PMid:33672415.

SINAGA, R.A., KURNIASIH, B. and SUSILA PUTRA, E.T., 2021. Growth and yield of soybean as a response of the fertilization of NPK compound produced with spent and deoiled bleaching earth filler. *Caraka Tani : Majalah Ilmiah*, vol. 36, no. 1, pp. 11-19. https://doi.org/10.20961/carakatani.v36i1.35682.

SUNARTONO., LENGGOGENI., HANDAYANI, I.D., SETIAWAN, H., ADIARSO, A., NELLY, A., HERMAWAN, E., WIJONO, R.A., WICAKSANA, D.E.P., MARSUDI, A., SETIYADI, E.D., SAPARUDIN., SETIADI, S., FERABIANIE, A.L. and DEWI, Y.R., 2025. Assessing competitiveness and sustainability of the cooking oil industry through the valuation of eco-efficiency on the utilization of spent bleaching earth. *Case Studies in Chemical and Environmental Engineering*, vol. 11, pp. 101176. https://doi.org/10.1016/j.cscee.2025.101176.

TOLEDO, M., 2016 [viewed 5 February 2026]. *Manejo de suelos ácidos en las zonas altas de Honduras: conceptos y métodos* [online]. Honduras: Dirección de Ciencia y Tecnología Agropecuaria, Instituto Interamericano de Cooperación para la Agricultura, 151 p. Available from: https://repositorio.iica.int/bitstream/handle/11324/3108/BVE17069071e.pdf;jsessionid=8636C4F0181DC9

VELA, G., LÓPEZ, J. and RODRÍGUEZ, M., 2012. Niveles de carbono orgánico total en el Suelo de Conservación del Distrito Federal, centro de México. *Investigaciones Geográficas*, no. 77, pp. 18-30. https://doi.org/10.14350/rig.31007.

VÉLEZ CHANG, Y.J., 2024. *Nutrición sostenible a base de residuos de tierra de blanqueo en betarraga (Beta vulgaris L.) para mayor rendimiento, Barranca 2023*. Huacho: Universidad Nacional José Faustino Sánchez Carrión, 66 p. Tesis de Doctora en Ciencias Ambientales.

VÉLEZ CHANG, Y.J., VÉLEZ CHANG, D.J., MAZUELOS CARDOZA, C.M. and LINARES CABRERA, V.J., 2022. Aprovechamiento de compost a base de residuos de tierra de blanqueo para mayor rendimiento de betarraga *(Beta vulgaris* L.), Barranca. *Revista Alfa*, vol. 6, no. 18, pp. 491-502. https://doi.org/10.33996/revistaalfa.v6i18.185.

VICIDOMINI, C., PALUMBO, R., MOCCIA, M. and ROVIELLO, G.N., 2024. Oxidative processes and xenobiotic metabolism in plants: mechanisms of defense and potential therapeutic implications. *Journal of Xenobiotics*, vol. 14, no. 4, pp. 1541-1569. https://doi.org/10.3390/jox14040084. PMid:39449425.

VILAR, J., PEREIRA, J. E., URIETA, D., MENOR, A., CAÑO, S., BARREAL, J., VELASCO, M.D.M., PUENTES, R., GHEDIRA, A., REYES, F. and ACISCLO, E., 2018 [viewed 3 January 2026]. *La olivicultura internacional: difusión histórica, análisis estratégico y visión descriptiva* [online]. España: Fundación Caja Rural de Jaén. Available from: https://drive.google.com/file/d/1EjpTj0OX88Ux-3yk30feAMSy17gzHfqY/view

WANG, L., ZHENG, J., ZHOU, G., LI, J., QIAN, C., LIN, G., LI, Y. and ZUO, Q., 2023. Moderate nitrogen application improved salt tolerance by enhancing photosynthesis, antioxidants, and osmotic adjustment in rapeseed (*Brassica napus* L.). *Frontiers in Plant Science*, vol. 14, pp. 1196319. https://doi.org/10.3389/fpls.2023.1196319. PMid:37255564.

ZAYED, O., HEWEDY, O.A., ABDELMOTELEB, A., ALÍ, M., YOUSSEF, M.S., ROUMIA, A.F., SEYMOUR, D. and YUAN, Z.C., 2023. Nitrogen journey in plants: from uptake to metabolism, stress response, and microbe interaction. *Biomolecules*, vol. 13, no. 10, pp. 1443. https://doi.org/10.3390/biom13101443. PMid:37892125.