Agric Res
https://doi.org/10.1007/s40003-024-00723-9

BRIEF RESEARCH ARTICLE

Response of Carrots (*Daucus carota*) on the Growth, Yield, and Nutritional Composition to Varying Poultry Manure Rates

Festus Onyebuchi Eze[1] · Chisenga Emmanuel Mukosha[1] · Chukwunyere Anozie[1] · Jan Moudrý[1] · Shahzaib Ali[1] · Mohammad Ghorbani[1] · Elnaz Amirahmadi[1] · Sadia Babar Baloch[1] · Kayode Paul Baiyeri[2]

Received: 26 September 2023 / Accepted: 18 March 2024

Abstract Carrot cultivation in south-eastern Nigeria could reduce the need to transport carrots from northern regions. To explore this, a field experiment with three replications was carried out in Nsukka, south-eastern Nigeria, focusing on four carrot varieties (Carotte Touchon, Touchon Mega, Super Mega, and Touchon France) and three poultry manure rates (0, 10, and 20 t ha^{-1}). The study revealed that Carotte Touchon had the highest root production (11.6 t ha^{-1}) with 20 t ha^{-1} of manure, followed by 7.5 t ha^{-1} at 10 t ha^{-1}, while Touchon Mega had the lowest root yield (1.4 t ha^{-1}) in the control group. Proximate quality of carrots was mostly unaffected by the varieties, except for fat content. The study found significant variations in vitamins A, C, and E, phytochemicals (phytate, tannins, and oxalate), and minerals (Fe, Mg, Na, and K) among the varieties, although no impact on Zn and Ca was observed. This research suggests that carrots have substantial growth potential in south-eastern Nigeria, offering a solution to vitamin and mineral deficiencies prevalent in this area. Additionally, Carotte Touchon with either 20 t ha^{-1} or 10 t ha^{-1} of poultry manure is recommended for optimal carrot cultivation in this region.

Keywords Carrots · Crop yield · Growth · Nutrition · Poultry manure

✉ Festus Onyebuchi Eze
ezefes00@fzt.jcu.cz

Chisenga Emmanuel Mukosha
mukosc00@fzt.jcu.cz

Chukwunyere Anozie
anozic00@fzt.jcu.cz

Jan Moudrý
jmoudry@fzt.jcu.cz

Shahzaib Ali
alisha00@fzt.jcu.cz

Mohammad Ghorbani
ghorbm00@fzt.jcu.cz

Elnaz Amirahmadi
amirae00@fzt.jcu.cz

Kayode Paul Baiyeri
paul.baiyeri@unn.edu.ng

[1] Department of Agroecosystems, Faculty of Agriculture and Technology, University of South Bohemia, Ceske Budejovice, Ceske Budejovice, Czech Republic

[2] Department of Crop Science, University of Nigeria Nsukka, Nsukka, Enugu State, Nigeria

Introduction

The carrot (*Daucus carota L.*) is a member of the Apiaceae family and is cultivated worldwide [48].Carrot cultivation is valuable worldwide because carrots contain essential nutrients like carotene, a precursor to vitamin A. [60]. Carrots originated from Asia with long, slender, and purple-yellow roots. These colors, along with white and orange, are still in use today, with orange or orange-red being the most common [54]. Carrot roots come in a variety of forms, ranging from long and thin to short and thick and the shape of the root might be cylindrical, conical, pointed, spherical, or blunt [52]. Carrots can be an important vegetable to address food insecurity and currently, large quantities of them are also canned or frozen, either alone or in combination with other vegetables [28]. Carrot is a herbaceous plant of different cultivars containing about 86–87% water, 7% sugar, 6.46–10.73% protein, 1% ash, 1.97–4.31% fat, and 7.18–8.87% fiber comprising mainly of cellulose with small proportions of

Published online: 15 April 2024

hemicelluloses and lignin [15]. Carrot is an excellent source of vitamin A and C as well as calcium pectate, an extraordinary pectin fiber that has been found to have cholesterol lowering properties [14]. It is also rich in minerals such as calcium, potassium, magnesium, manganese, molybdenum, and phosphorous. Carrots have a high level of Beta-carotene which gives carrot its distinctive orange color and it contains lesser amounts of Alpha and Gamma carotene [51]. The Alpha and Beta carotene are partly metabolized into vitamin A in humans, a vitamin which is necessary in human nutrition for proper vision, reproductive health, cell formation and cell communication [19]. In smaller amounts, carrots contain essential oils, carbohydrates (free sugar such as sucrose, glucose, fructose and xylose) and nitrogenous composites. Carrots are also rich in antioxidants which help to prevent cellular damage from free radicals [47]. The nutritional food value of carrot changes depending on whether it is served fresh or cooked. Studies have found that cooked carrots actually contain more antioxidants than raw carrots.

Carrot yields per unit area in most developing countries remain below the recommended world average [53]. In Nigeria, cool-season vegetables are mainly grown in high-altitude regions of Northern districts where a mild sub-tropical climate prevails [6]. Hence, production of carrots in a diverse variety of soils and environmental conditions is needed to increase carrot production in the country [56]. Although the carrot crop has a lot of potential and has been widely planted in Nigeria for a long time, taking up roughly 27,000 ha of available land, primarily in the North, its yield per hectare is still very poor [39]. The average yield of carrots in Nigeria is low with 15 t ha^{-1} compared to the USA with an amount of 170 t ha^{-1} [25]. Many production issues, including improper nutrient application and fertilizer type, lack of appropriate spacing, irrigation, planting date, and choice of variety have all contributed to the low carrot yield in this region [2, 23, 41].

Furthermore, one of the most severe challenges in carrot cultivation in Nigeria is the type and usage of fertilizer [3]. The low yield per hectare in Nigeria has been attributed to inadequate farming techniques, including the neglect of agro-industrial residues like organic fertilizers, among other contributing factors.

[42, 44]. For instance, there have been reports of the excessive application of animal manure across various plant cultivation practices in Nigeria, with a particular emphasis on carrot farming [7, 9, 33]. However, using animal manure alone could have negative consequences for human health and the environment [8]. On the other hand, mineral fertilizers are becoming increasingly expensive, and Nigerian farmers are unable to purchase them for vegetable crop cultivation [5]. In this circumstance, using locally available resources such as poultry manure will be beneficial in enhancing soil quality such as soil structure, and microbial biomass, and so contributing to increased plant production especially carrot cultivation in Nigeria [17, 38]. As a result, vegetable growers may be able to boost crop yields while using less chemical fertilizer by using locally generated poultry manure [9]. Organically farmed fruits and vegetables have more minerals and vitamins than those grown conventionally [50].

Several attempts have been undertaken in south-eastern Nigeria to boost the yield potential of root crops while ignoring carrots [10, 18, 56]. Previous studies focused mostly on the usage of mineral fertilizers. However, this type of fertilizer if endlessly used by farmers will result in loss of soil fertility and soil health [45]. The ongoing utilization of mineral fertilizers in crop cultivation will affect both environmental sustainability and human health [26]. In this respect, organic fertilizers such as poultry manure, farmyard manure (FYM), and cattle manure are increasingly important for productivity and quality [5, 7, 17].

In Nigeria, about 932.5 metric tonnes of commercial poultry manure was reported to be annually produced [4]. The current annual production of poultry manure in Nigeria is uncertain, but it is anticipated to be significantly higher than the previously mentioned figures. Poultry manure, being a bulky organic resource, relieves soil compaction and promotes aeration, while also providing critical plant nutrients and organic matter, increasing soil microbial establishment, and accumulating surplus humus content [5, 38]. Poultry manure is known for its elevated nitrogen content, which poses a risk of water pollution through leachate [37]. This could be mitigated by optimizing application rates, incorporating manure into soil, and using cover crops. Establish buffer zones and adhere to regulations to prevent excess nitrogen runoff [21]. Regular monitoring and farmer education are essential for sustainable and responsible manure management.

Organically grown fruits, vegetables, and food crops have a substantially greater market value, both internationally and domestically [35]. They are recognized to be residue-free, making them beneficial to the environment and human health [45]. The research on the use of organic fertilizers in vegetable crops, particularly carrots is very much limited [30, 59]. There is a lack of specific recommendations for poultry manure use in southeast Nigeria, with minimal research on its impact on carrot yield. Therefore, our research focuses on investigating the effects of poultry manure on both carrot yield and nutrient quality in the unique agricultural context of south eastern Nigeria. This study aims to contribute valuable insights to the existing knowledge gap and offer practical recommendations for optimizing carrot production in the region.

Materials and Methods

Experimental Site

The experiment was conducted between the month of June and September, 2022 at the Department of Crop Science Teaching and Research farm of the University of Nigeria, Nsukka (07°29'N; 06°51'E, and 400 m a.m.s.l.). Nsukka has a lowland humid tropical condition with bimodal annual rainfall distribution, of 1155–1955 mm). The mean annual temperature and the relative humidity in this region 30 °C, and 68%, respectively.

Meteorological data of experimental site are presented in Supplementary Table 1. The soil of the experimental area is generally characterized as Ultisol based on USDA classification. The usual soil pH in water is quite acidic with low in organic matter and fertility level. Some basic analyses of experimental soil before planting are presented in Supplementary Table 2.

Treatment Allocation and Experimental Design

The planting was conducted on a double row with a spacing of 100 cm by 40 cm in a sub-plot of twelve planting holes giving rise to the population density of 144,000 stands of carrot per hectare. A 4 × 3 split plot experiment assigned in a randomized complete design replicated three times. The main plots comprised four carrot varieties including Carotte Touchon, Touchon Mega, Super Mega, Touchon France, while the sub-plot consisted of three poultry manure rates: 0 (Control), 10, and 20 t ha^{-1}. The manure were freshly harvested from the University of Nigeria Nsukka Research farm. The poultry manure undergone a composting process for 90 days, during which it has exhibited characteristics indicative of sufficient maturity. The compost is now characterized by a dark brown colour, an earthy and pleasant odour, a crumbly texture, and a decrease in temperature over time. These visual and olfactory cues suggest that the poultry manure has reached a state of maturity, making it suitable for use as a nutrient-rich and stable compost. Workers used personal protective equipment (gloves, goggles, masks) for handling poultry manure, with dedicated coveralls to prevent contamination. To ensure a safe working environment, strict hand hygiene was followed after handling tasks, which includes washing and using hand sanitizer Weeding was done manually as at when necessary. No chemical plant protection were used and insects were picked by hand.

Plant Data

During plant growth, seedling emergence (SE) was measured as follow:

$$\text{SE}\ (\%) = \frac{No\ of\ Emerged\ seeds \times 100}{Total\ sown\ seeds}$$

After harvesting, weights of whole and individual parts of plants biomass (g) were measured to calculate harvest index (HI) as follows:

$$\text{HI}\ (\%) = \frac{Economical\ yield\ (underground\ biomass) \times 100}{Biological\ yield\ (Whole\ plant\ biomass)}$$

Nutritional Analysis

The carrot varieties were collected from the experimental site of the Department of crop science, University of Nigeria, Nsukka. The soil texture from where the samples were harvested is sandy clay loam (Supplementary Table 2). Five carrots roots were used as sampling unit for each variety. The four varieties of carrot under investigation include: Carotte Touchon, Touchon France, Touchon Mega, and Super Mega. The samples were harvested 90 days after cultivation. The samples were then carefully cleaned and air-dried. The identical samples were mashed together, placed in marked, sterile-clean transparent Ziploc plastic bags, and stored in a refrigerator at 2.5 °C until analysis. Freshly harvested carrot roots underwent proximate analysis following AOAC, 2005 [11] for moisture, ash, and carbohydrate content. Mineral levels were determined using AOAC, 2003 [12] like atomic absorption spectrometry and flame photometry. Crude protein, fiber, and fat levels were assessed with Pearson, 1993 [46]. Phytochemical analysis, including phytate, oxalate, and tannins, followed Harborne, 1973 [29] and vitamin identification was conducted using AOAC, 2003 [1]. Three independent analyses were performed on each sample.

Data Analysis

All data collected were subjected to ANOVA using GENSTAT (2010 Edition), and significant differences between treatment means were determined using Fisher's least significant difference at the 5% probability level, Excel 2020 was used to draw all the figures.

Results

Seedling Emergence (%)

The response of seedling emergence (%) to varied manure rates showed no significant difference across the manure rates (Fig. 1). But the application of 10 t ha^{-1} poultry manure had the higher mean values for the percentage emergence of carrot seedlings on day 21 after planting, although the mean values were not significantly different from no manure application and 20 t ha^{-1} application.

Plant Yield and Growth Measurements

The response of fresh yield and yield components of carrot on varied manure rates showed that whole-plant biomass, fresh leave weight, fresh root weight, harvest index, yield per bed, and yield per hectare significantly ($p < 0.05$) varied among the poultry manure rates (Table 1). The application of either 10 or 20 t ha^{-1} poultry manure significantly increased the whole plant biomass, fresh leaf weight, fresh root weight, yield per bed, and yield per hectare compared to the plant that did not receive manure.

With the exception of yield per bed, the interaction between variety and poultry manure had little impact on yield and its components as presented in Fig. 2. However, the variety Carotte Touchon which received 20 t ha^{-1} of poultry manure gave the highest yield per hectare of 11.6 t ha^{-1} and in the whole plant biomass yield of 820 g when compared with, Touchon Mega which received no manure and had the lowest root yield (1.4 t ha^{-1}). Although, the lowest harvest index (42.8%) was found on Super Mega plots which received no manure, while the best harvest index (59.8%) was observed on the plots of Carotte Touchon that received 10 t ha^{-1} of poultry manure.

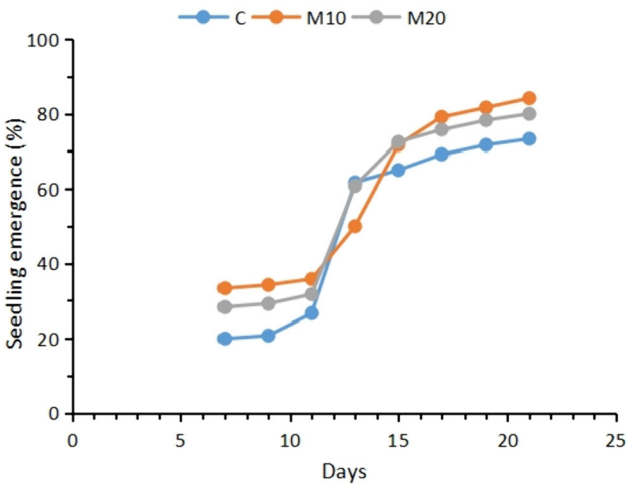

Fig. 1 Seedling emergence (%) responses of carrot to varied poultry manure rate. *C* control; *M10* manure 10%, *M20* manure 20%

Quality of Fresh Carrot Root

Except for the fat content, the influence of varieties on proximate quality was statistically similar for practically all proximate traits (Table 2). There was no specific pattern observed in the arrangement of the highest and lowest nutrient values among the carrot varieties. Despite the lack of significant differences in nearly all proximate characteristics, the research indicates that carrots offer a substantial source of protein, ash, carbohydrates, and moisture.

Vitamin Composition of Fresh Carrot

Variety had a significant impact on the content of vitamins, particularly vitamins A, C, and E. ($p < 0.05$) (Table 3). The results of the experiment indicated a significant difference ($p < 0.05$) in the vitamin A content among the carrot varieties. Carotte Touchon demonstrated the highest vitamin A content (48.2 mg), surpassing Touchon Mega (43.7 mg), Super Mega (35.9 mg), and Touchon France (30.4 mg). Despite the absence of a specific pattern in the arrangement of highest and lowest values for this nutrient among the varieties, Touchon France consistently exhibited the lowest vitamin A content compared to the other varieties. The highest vitamin C content per 100 g fresh weight (FW) was found in Touchon France (25.6 mg), followed by Touchon Mega (20.6 mg), Carotte Touchon (3.8 mg), and Super Mega (2.5 mg). However the higher content of vitamin E was recorded in Touchon Mega (6.8 mg) while Carotte Touchon had the least content of vitamin E (2.2 mg).

Phytochemical Composition of Fresh Carrot Roots

The effect of varieties on phytochemical composition was significant ($p < 0.05$) across phytate, tannin and oxalate (Table 4). The result of the experiment revealed that Touchon Mega had the highest content of anti-nutrient across the phytate, tannin and oxalate whereas Super Mega had the lowest content of anti-nutrient with the same sequence.

Mineral Composition of Fresh Carrot Root

The main effect of varieties on mineral composition was statistically similar in zinc and calcium (Table 5). However Touchon Mega had higher mean value of iron (2.7 mg), magnesium (6.8 mg), sodium (72 mg) and potassium (253.5 mg) respectively whereas the lowest mean value of iron and magnesium was recorded in Touchon France with

Table 1 Main effects of poultry manure on fresh carrot yield and yield components

Manure (t ha^{-1})	WPB (g)	FLW (g)	FRW (g)	HI (%)	Y/BED (Kg)	Y/HA (t ha^{-1})
0	159.0	82.0	78.0	48.5	0.5	1.9
10	351.0	150.0	193.0	55.5	1.2	4.6
20	427.0	188.0	239.0	55.2	1.4	5.6
F-$LSD_{(0.05)}$	133.3	69.4	71.2	3.9	0.4	1.6

WPB Whole plant biomass, *FLW* Fresh leave weight, *FRW* Fresh root, weight, *HI* Harvest index, Y*/HA* Yield/hectare, *Y/BED* Yield/ bed *FLSD* fishers least significant difference

(2.2 mg) and (4.4 mg) respectively and Super Mega also had the lowest value of sodium (40.5 mg) and potassium (101.6 mg).

Discussion

The results of this study demonstrate a noteworthy positive impact of poultry manure on various aspects of carrot cultivation. Plots treated with poultry manure exhibited higher percentages of seedling emergence, overall yields, and yield components compared to untreated plots. This improvement in performance suggests that the nutrient dynamics, including the release and availability of essential nutrients for plant absorption and utilization, were positively influenced by the application of poultry manure.

Poultry manure, known for its richness in nitrogen and substantial quantities of phosphorus and potassium, serves as an effective fertilizer. The nutrient composition of poultry manure makes it valuable for enhancing soil characteristics and fertility. In this study, the positive outcomes in plots treated with poultry manure can be attributed to the favorable influence on soil nutrient capacity and the release of nutrients available to the plants.

It is important to note that carrot cultivation in Nsukka faces specific soil challenges, characterized as ultisol with well-drained ferralitic sandy loam and high acidity. According to Anozie and Baiyeri [9], carrots typically thrive in well-drained soil with a pH ranging from 6.5 to 7. However, the existing soil conditions in Nsukka may limit the availability of nutrients to plants [22]. The application of poultry manure in this context is seen as a potential solution, potentially ameliorating soil nutrient capacity and addressing the limitations imposed by the soil characteristics. The findings align with prior research by Anozie and Baiyeri [9], who reported significant positive effects of manure application on seedling emergence and overall marketable root yields in carrot plots.

The variations in yields and yield components observed among the four carrot varieties (Carotte Touchon, Touchon Mega, Super Mega, and Touchon France) in this experiment may be attributed to the genetic diversity within each plant population. Genetic diversity is pivotal for a species to effectively adapt to different environmental conditions. In the context of this study, it is plausible that Carotte Touchon displayed superior adaptation to the agroecology of Nsukka compared to the other varieties. This aligns with the findings of [43], highlighting that genetic diversity within a species facilitates adaptation to changing soil, climatic conditions, and other environmental factors.

The synergistic effects noted between carrot varieties and poultry manure levels suggest that higher yields were achieved in plots treated with 20 t ha^{-1} and 10 t ha^{-1} manure rates. This suggest that the genetic diversity within the carrot varieties, when coupled with nutrient-rich poultry manure, positively influenced plant performance.

The increased yields in plots treated with poultry manure can be attributed to the manure's capacity to release essential nutrients to the plants and facilitate mineralization [22]. The efficient absorption of these nutrients by the plants likely contributed to the observed higher yields. This aligns with the concept that the nutrient composition of poultry manure improves soil fertility, providing essential elements for robust plant growth.

The genetic diversity among carrot varieties and their interaction with poultry manure emphasize the multifaceted factors influencing crop performance. These findings underscore the significance of considering both genetic factors and soil amendments, such as poultry manure, to optimize carrot cultivation in the specific agroecological conditions of Nsukka. This comprehensive approach enhances our understanding of the intricate relationships between genetic diversity, soil fertility, and environmental adaptation in agricultural systems.

The examination of proximate concentration across various carrot varieties revealed minimal differences, except for fat content. Notably, carrots emerged as an outstanding source of moisture and carbohydrates, boasting an average moisture level of approximately 81%. This high moisture content suggests that carrots could potentially contribute to body rehydration. However, it's important to

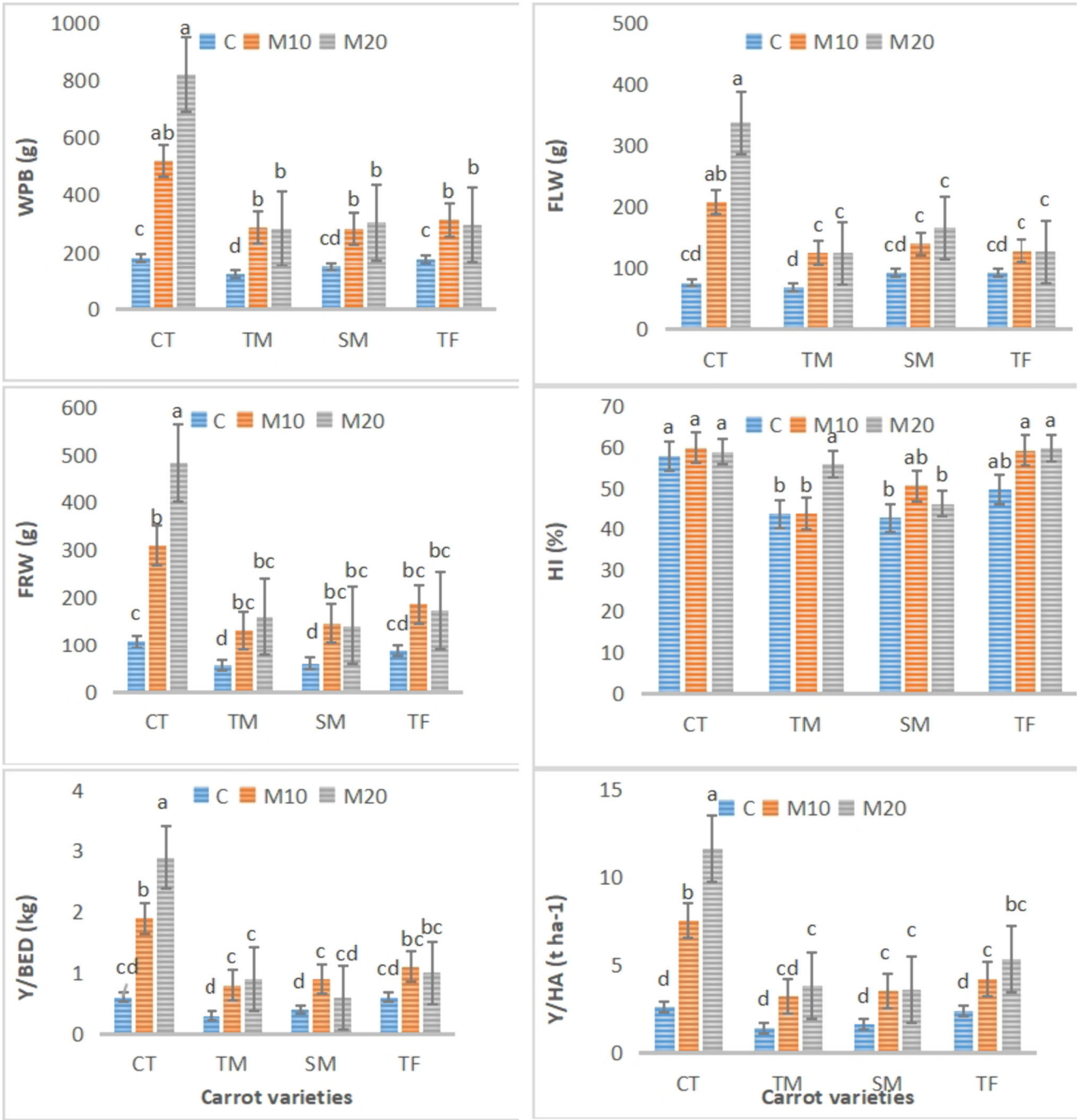

Fig. 2 Interaction effects of varieties and poultry manure rates on carrot yield ($p < 0.05$). *C* control, *M10* manure 10 t ha^{-1}, *M20*: manure 20 t ha^{-1}. *Abbreviations for carrot varieties are as follows* Carotte Touchon (CT), Touchon Mega (TM), Super Mega (SM), Touchon France (TF). The columns sharing different letters are significantly different at $p < 0.05$. The error bars represent standard deviations

acknowledge that this characteristic, while beneficial for consumption, could pose challenges in terms of storage due to its propensity to promote the growth of microorganisms, potentially shortening the shelf life of stored carrots.

In terms of nutritional components, the protein content was relatively low at 4.0%, indicating that carrots are not a substantial source of protein. The ash content was approximately 1.3%, while crude fiber, essential for digestion, was consistently present at around 1.0% across all varieties. The inclusion of crude fiber in carrots enhances their desirability as a dietary component, promoting digestive health.

The vitamin profile of carrots revealed a remarkable concentration of vitamin A, ranging from 30 to 48 mg.

Table 2 Main effect of varieties on proximate quality of carrot root

Varieties	Protein (%)	Fat (%)	Fibre (%)	Ash (%)	Carbohydrate (%)	Moisture (%)
Carotte Touchon	3.9	0.3	0.9	1.2	12.5	81.7
Touchon Mega	3.4	0.3	1.1	1.5	12.1	82.0
Super Mega	3.6	0.5	1.0	1.5	12.1	81.3
Touchon France	4.1	0.6	1.1	1.4	12.3	81.4
F-LSD (0.05)	NS	0.1	NS	NS	NS	NS

Table 3 Main effect of varieties on vitamins composition of carrot roots

Varieties	Vitamin A (mg)	Vitamin C (mg)	Vitamin E (mg)
Carotte Touchon	48.2	3.8	2.2
Touchon Mega	43.7	20.6	6.8
Super Mega	35.9	2.5	3.0
Touchon France	30.4	25.6	4.1
F-LSD (0.05)	3.9	0.8	0.9

Table 4 Main effect of varieties on phytochemical composition of carrot root

Varieties	Phytate (mg)	Tannin (mg)	Oxalate (mg)
Carotte Touchon	0.1	11.1	9.1
Touchon Mega	0.2	11.2	9.9
Super Mega	0.02	7.4	1.0
Touchon France	0.2	11.1	8.5
LSD (0.05)	0.03	0.9	1.3

Table 5 Main effect of varieties on mineral composition of carrot root

Varieties	Iron mg	Zinc mg	Calcium mg	Magnesium mg	Sodium mg	Potassium mg
Carotte Touchon	2.4	0.4	76.6	4.8	41.8	183.4
Touchon Mega	2.7	0.4	74.1	6.8	72.0	253.5
Super Mega	2.4	0.4	77.6	4.9	40.5	101.6
Touchon France	2.2	0.3	75.9	4.4	69.5	185.1
LSD (0.05)	0.2	NS	NS	0.7	3.7	14.7

This signifies that carrots serve as an excellent source of vitamin A, crucial for maintaining clear vision and overall eye health. The findings emphasize the potential of incorporating carrots into the diet to support ocular well-being.

The experimental results underscore the nutritional richness of carrots, particularly in terms of moisture, carbohydrates, and essential vitamins. While their high moisture content presents considerations for storage, the myriad health benefits associated with carrot consumption, including vitamin A support for eye health, make them a valuable addition to a balanced diet.

The result also revealed that carrots will be a good source of vitamin C and vitamin E. Vitamin C is good for the body's normal metabolism, and can also be used in the prevention of scurvy and in wound healing and tissue repair [50]. Vitamin E functions as a fat-soluble antioxidant that guards against cellular damage and lowers the risk of several illnesses, including cancer and heart ailments [54]. According to their mineral makeup, carrot roots include

significant levels of potassium, calcium, sodium, magnesium, and iron. The minerals (K, Ca, Na, and Mg) found in carrot roots in this experiment were similar to those reported by [16, 34]. Sodium and potassium are important intracellular and extracellular cations respectively. Sodium is involved in the regulation of plasma volume, acid–base balance, and nerve and muscle contraction [51].

Sodium remains one of the major electrolytes in the blood. Without sodium, the body cannot maintain its hydration and would become dehydrated [12]. Calcium is necessary for the coagulation of blood, the proper functioning of the heart and nervous system and the normal contraction of muscles [32]. Its primary role is to support the development of bones and teeth. Magnesium is a component of chlorophyll and is a crucial mineral element in relation to ischemic heart disease and calcium metabolism in bones [24].

Iron is essential for cell-mediated immunity, infection control, and haemopoiesis [20]. The most frequent dietary deficit, iron deficiency anemia, affects more than a billion people worldwide, according to estimates [36]. The consequences of iron deficiency include reduced work capacity, impairments in behaviour and intellectual performance and decrease resistance to infection [27]. Over 50 enzymes in the body contain zinc, which is essential for the immune system to operate normally [58]. An estimated 17.3% of the world population is reported to be at risk of inadequate zinc intake [57]. According to Kennedy [31], zinc levels in Nigerian children between the ages of 5 and 60 months are low and consistent with the findings of other studies, indicating the necessity of frequent supplementation [31]. Consuming carrots could be another strategy to address this issue in young children.

The outcome of this research also showed that phytate, tannin, and oxalate were found in the carrot root, but in very low concentrations that do not endanger consumer's health. Phytochemicals are bioactive substances that are well-known for their positive effects on health [49]. Phytochemicals' anti-inflammatory, antioxidant, plasma lipid-modifying, and anti-tumour characteristics aid in the prevention of cancer and cardiovascular illnesses [13].

These findings provide practical insights for individuals seeking to optimize their nutritional intake and make informed dietary choices.

Conclusions

Carrots have a huge potential to thrive in south-eastern Nigeria and to supplement the vitamin and mineral deficits in foods that are common in developing nations. Specific recommendations about the use of poultry manure and varieties are lacking in south-eastern Nigeria. Therefore, this finding would be a base for future research in south-eastern Nigeria to come up with the right recommendations about the use of poultry manure and varieties for carrot production., we therefore conclude that the application of poultry manure at a rate of either 10 t ha^{-1} or 20 t ha^{-1} boosted carrot growth, yield and nutritional composition with Carotte Touchon being the most adapted variety.

Author Contributions Conceptualization, EFO; methodology, EFO; software, EFO, CEM, and CA; validation, JM, EFO, CEM, and CA; formal analysis, EFO, CEM, and CA; investigation, EFO, CEM, CA, SA, SBB, and KPB; resources, JM; data curation, CA, SA, SBB, and KPB; writing—original draft preparation, EFO, CEM, and JM; writing—review and editing, MG, and EA; visualization, EFO; supervision, JM; project administration, EFO; funding acquisition, JM All authors have read and agreed to the published version of the manuscript.

Funding Open access publishing supported by the National Technical Library in Prague.

Data Availability Not applicable.

Declarations

Conflicts of interest The authors declare no conflict of interest.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40003-024-00723-9.

References

1. AOAC (1990) Official methods of analysis, 15th edn, Association of Official Analytical Chemist. Washington DC
2. Adekiya AO, Aremu C, Agbede TM, Olayanju A, Ejue WS, Adegbite KA, Olayiwola IE, Ajiboye B, Oni AT (2021) Soil productivity improvement under different fallow types on Alfisol of a derived savanna ecology of Nigeria. Heliyon 7:e06759. https://doi.org/10.1016/j.heliyon.2021.e06759
3. Adesida IE, Nkomoki W, Bavorova M, Madaki MY (2021) Effects of agricultural programmes and land ownership on the adoption of sustainable agricultural practices in Nigeria. Sustainability 13:7249. https://doi.org/10.3390/su13137249

4. Adewumi AA, Adewumi IK, Olaleye VF (2011) Livestock waste-menace: fish wealth-solution. Afr J Environ Sci Technol 5:149–154
5. Adeyemo AJ, Akingbola OO, Ojeniyi SO (2019) Effects of poultry manure on soil infiltration, organic matter contents and maize performance on two contrasting degraded Alfisols in southwestern Nigeria. Int J Recycl Org Waste Agricult 8:73–80. https://doi.org/10.1007/s40093-019-0273-7
6. Adhikari U, Nejadhashemi AP, Woznicki SA (2015) Climate change and eastern Africa: a review of impact on major crops. Food Energy Secur 4:110–132. https://doi.org/10.1002/fes3.61
7. Agbede TM (2021) Effect of tillage, biochar, poultry manure and NPK 15-15-15 fertilizer, and their mixture on soil properties, growth and carrot (*Daucus Carota* L.) yield under tropical conditions. Heliyon 7:e07391. https://doi.org/10.1016/j.heliyon.2021.e07391
8. Ajayeoba TA, Atanda OO, Obadina AO, Bankole MO, Adelowo OO (2016) The incidence and distribution of *Listeria Monocytogenes* in ready-to-eat vegetables in south-western Nigeria. Food Sci Nutr 4:59–66. https://doi.org/10.1002/fsn3.263
9. Anozie CC, Baiyeri KP (2022) Effects of tillage methods and poultry manure rates on the production of carrot (*Daucus Carota* L) in Nsukka, Southeast Nigeria. J Hortic For 14:42–48. https://doi.org/10.5897/JHF2022.0691
10. Anyanwu CN, Ibeto CN, Ezeoha SL, Ogbuagu NJ (2015) Sustainability of cassava (*Manihot Esculenta* Crantz) as industrial feedstock, energy and food crop in Nigeria. Renew Energy 81:745–752. https://doi.org/10.1016/j.renene.2015.03.075
11. AOAC (2005) Official method of Analysis, 18th edn. Association of Officiating Analytical Chemists, Washington DC, Method 935.14 and 992.24
12. AOAC (2003) Official methods of analysis of the association of official's analytical chemists, 17th edn. Association of Official Analytical Chemists, Arlington, Virginia
13. Bachheti RK, Worku LA, Gonfa YH, Zebeaman M, Deepti PDP, Bachheti A (2022) Prevention and treatment of cardiovascular diseases with plant phytochemicals: a review. Evid Complement Altern Med 2022:1–21. https://doi.org/10.1155/2022/5741198
14. Bao B, Chang KC (1994) Carrot pulp chemical composition, color, and water-holding capacity as affected by blanching. J Food Sci 59:1159–1161. https://doi.org/10.1111/j.1365-2621.1994.tb14666.x
15. Boadi NO, Badu M, Kortei NK, Saah SA, Annor B, Mensah MB, Okyere H, Fiebor A (2021) Nutritional composition and antioxidant properties of three varieties of carrot (*Daucus Carota* L.). Sci Afr 12:e00801. https://doi.org/10.1016/j.sciaf.2021.e00801
16. Bonasia A, Conversa G, Lazzizera C, Gambacorta G, Elia A (2021) Morpho-biometrical, nutritional and phytochemical characterization of carrot landraces from Puglia Region (Southern Italy). Sustainability 13:3940. https://doi.org/10.3390/su13073940
17. Busari MA, Salako FK (2015) Soil hydraulic properties and maize root growth after application of poultry manure under different tillage systems in Abeokuta, southwestern Nigeria. Arch Agron Soil Sci 61:223–237. https://doi.org/10.1080/03650340.2014.924620
18. Chukwuone NA, Amaechina EC (2021) Factors affecting climate change coping strategies used by smallholder farmers under root crop farming systems in derived savannah ecology zone of Nigeria. Environ Develop 39:100627. https://doi.org/10.1016/j.envdev.2021.100627
19. Clagett-Dame M, Knutson D (2011) Vitamin A in reproduction and development. Nutrients 3:385–428. https://doi.org/10.3390/nu3040385
20. Cronin SJF, Woolf CJ, Weiss G, Penninger JM (2019) The role of iron regulation in immunometabolism and immune-related disease. Front Mol Biosci 6:116. https://doi.org/10.3389/fmolb.2019.00116
21 Dróżdż D, Wystalska K, Malińska K, Grosser A, Grobelak A, Kacprzak M (2020) Management of poultry manure in Poland—current state and future perspectives. J Environ Manag 264:110327. https://doi.org/10.1016/j.jenvman.2020.110327
22. Ehtaiwesh AF (2022) The effect of salinity on nutrient availability and uptake in crop plants. J Appl Sci. https://doi.org/10.47891/sabujas.v0i0.55-73
23. Etim MA, Babaremu K, Lazarus J, Omole D (2021) Health risk and environmental assessment of cement production in Nigeria. Atmosphere 12:1111. https://doi.org/10.3390/atmos12091111
24. Fiorentini D, Cappadone C, Farruggia G, Prata C (2021) Magnesium: biochemistry, nutrition, detection, and social impact of diseases linked to its deficiency. Nutrients 13:1136. https://doi.org/10.3390/nu13041136
25. Food and Agriculture Organization Database. Food and Agriculture Statistics. Available online: https://www.fao.org/faostat
26. Ghorbani M, Konvalina P, Neugschwandtner RW, Kopecký M, Amirahmadi E, Bucur D, Walkiewicz A (2022) Interaction of biochar with chemical, green and biological Nitrogen fertilizers on nitrogen use efficiency indices. Agronomy 12:2106. https://doi.org/10.3390/agronomy12092106
27. Haas JD, Brownlie T (2001) Iron deficiency and reduced work capacity: a critical review of the research to determine a causal relationship. J Nutr 131:676S-690S. https://doi.org/10.1093/jn/131.2.676S
28. Han C, Li J, Jin P, Li X, Wang L, Zheng Y (2017) The effect of temperature on phenolic content in wounded carrots. Food Chem 215:116–123. https://doi.org/10.1016/j.foodchem.2016.07.172
29. Harborne JB (1973) Phytochemical methods. Chapman and Hall Ltd., London, pp 49–188
30. Ibukunoluwa Moyin-Jesu E (2015) Use of different organic fertilizers on soil fertility improvement, growth and head yield parameters of cabbage (*Brassica Oleraceae* L.). Int J Recycl Org Waste Agric 4:291–298. https://doi.org/10.1007/s40093-015-0108-0
31. Kennedy C, Chukwuebuka N, Uchenna E (2020) Serum zinc levels in apparently healthy children in Nigeria: are they acceptable. Niger Med J 61:291. https://doi.org/10.4103/nmj.NMJ_20_20
32. LeBrasseur N (2003) Calcium for strong clotting. J Cell Biol 160:980–980. https://doi.org/10.1083/jcb1607iti2
33. Maikai BV, Akubo DO (2019) Coliform count and isolation of *Escherichia Coli* in fresh fruits and vegetables sold at retail outlets in Samaru, Kaduna State, Nigeria. Niger Vet J 39:327. https://doi.org/10.4314/nvj.v39i4.5
34. Majkowska-Gadomska J, Majkowska-Gadomska J, Dobrowolski A, Mikulewicz E, Jadwisieńczak K (2017) Yield and mineral composition of storage roots of carrots (*Daucus Carota* L.) protected with biological methods. J Elem. https://doi.org/10.5601/jelem.2016.21.3.1286
35. Mditshwa A, Magwaza LS, Tesfay SZ, Mbili N (2017) Postharvest quality and composition of organically and conventionally produced fruits: a review. Sci Hortic 216:148–159. https://doi.org/10.1016/j.scienta.12.033
36. Miller JL (2013) Iron deficiency anemia: a common and curable disease. Cold Spring Harb Perspect Med 3:a011866–a011866. https://doi.org/10.1101/cshperspect.a011866
37. Nahm KH (2003) Evaluation of the nitrogen content in poultry manure. World's Poult Sci J 59(1):77–88. https://doi.org/10.1079/WPS20030004
38. Ngbede EO, Raji MA, Kwanashie CN, Kwaga JKP (2017) Antimicrobial resistance and virulence profile of Enterococci isolated from poultry and cattle sources in Nigeria. Trop Anim

Health Prod 49:451–458. https://doi.org/10.1007/s11250-016-1212-5
39. Ajayi EO, Akin-Idowu PR, Aderibigbe OO, Ibitoye D, Afolayan G, Adewale MO, Adesegun, AE, Ubi EB, (2022) Nigeria Root Vegetables: Production, Utilization, Breeding, Biotechnology and Constraints. In Root Vegetables. IntechOpen
40 Obalum SE, Obi ME (2010) Physical properties of a sandy loam Ultisol as affected by tillage-mulch management practices and cropping systems. Soil Tillage Res 108(1):30–36. https://doi.org/10.1016/j.still.2010.03.009
41. Olugasa TT, Odesola IF, Oyewola MO (2014) Energy production from biogas: a conceptual review for use in Nigeria. Renew Sustain Energy Rev 32:770–776. https://doi.org/10.1016/j.rser.2013.12.013
42. Omotayo AO (2020) Parametric assessment of household's food intake, agricultural practices and health in Rural South West, Nigeria. Heliyon 6:e05433. https://doi.org/10.1016/j.heliyon.2020.e05433
43 Onda Y, Mochida K (2016) Exploring genetic diversity in plants using high-throughput sequencing techniques. Curr Genom. https://doi.org/10.2174/1389202917666160331202742
44. Oyetunde-Usman Z, Olagunju KO, Ogunpaimo OR (2021) Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers in Nigeria. Int Soil Water Conserv Res 9:241–248. https://doi.org/10.1016/j.iswcr.2020.10.007
45. Pahalvi HN, Rafiya L, Rashid S, Nisar B, Kamili AN (2021) Chemical fertilizers and their impact on soil health. In: Dar GH, Bhat RA, Mehmood MA, Hakeem KR (eds) Microbiota and biofertilizers, vol 2. Springer International Publishing, Cham, pp 1–20
46. Pearson D (1976) Chemical analysis of foods, 7th edn. Churchill, Livingstone, London, pp 7–11
47. Prasad K, Haq RU, Bansal V, Siddiqui M, Ilahy R (2016) Chapter 4 Carrot: Secondary Metabolites and Their Prospective Health Benefits. In: Siddiqui M, Prasad K (eds) Plant Secondary Metabolites. Apple Academic Press, Oakville, Canada, pp 107–194
48. Que F, Hou XL, Wang GL, Xu ZS, Tan GF, Li T, Wang YH, Khadr A, Xiong AS (2019) Advances in research on the carrot, an important root vegetable in the Apiaceae family. Hortic Res 6:69. https://doi.org/10.1038/s41438-019-0150-6
49. Samtiya M, Aluko RE, Dhewa T, Moreno-Rojas JM (2021) Potential health benefits of plant food-derived bioactive components: an overview. Foods 10:839. https://doi.org/10.3390/foods10040839
50. Sarpooshi HR, Haddadi M, Siavoshi M, Borghabani R (2017) Wound healing with Vitamin C. Transl Biomed. https://doi.org/10.21767/2172-0479.100139
51. Sharma KD, Karki S, Thakur NS, Attri S (2012) Chemical composition, functional properties and processing of carrot—a review. J Food Sci Technol 49:22–32. https://doi.org/10.1007/s13197-011-0310-7
52. Singh MN, Srivastava R, Yadav DI (2021) Study of different varietis of carrot and its benefits for human health: a review. J Pharmacogn Phytochem 10:1293–1299. https://doi.org/10.22271/phyto.2021.v10.i1r.13529
53. Tegen H, Jembere M (2021) Influences of spacing on yield and root size of carrot (*Daucus Carota* L.) under ridge–furrow production. Open Agric 6:826–835. https://doi.org/10.1515/opag-0062
54. Wang X (1999) Vitamin E and its function in membranes. Prog Lipid Res 38:309–336. https://doi.org/10.1016/S0163-7827(99)00008-9
55. Wang XJ, Luo Q, Li T, Meng PH, Pu YT, Liu JX, Zhang J, Liu H, Tan GF, Xiong AS (2022) Origin, evolution, breeding, and omics of Apiaceae: a family of vegetables and medicinal plants. Hortic Res 9:uhac076. https://doi.org/10.1093/hr/uhac076
56. Weli VE, Bajie S (2017) Adaptation of root crop farming system to climate change in Ikwerre Local Government Area of Rivers State, Nigeria. AJCC 06:40–51. https://doi.org/10.4236/ajcc.2017.61003
57. Wessells KR, Brown KH (2012) Estimating the global prevalence of zinc deficiency: results based on zinc availability in national food supplies and the prevalence of stunting. PLoS ONE 7:e50568. https://doi.org/10.1371/journal.pone.0050568
58. Wessels I, Maywald M, Rink L (2017) Zinc as a gatekeeper of immune function. Nutrients 9:1286. https://doi.org/10.3390/nu9121286
59. Wild PL, Kessel C, Lundberg J, Linquist BA (2011) Nitrogen availability from poultry litter and pelletized organic amendments for organic rice production. Agron J 103:1284–1291. https://doi.org/10.2134/agronj2011.0005
60. Zhao YH, Deng YJ, Wang YH, Lou YR, He LF, Liu H, Li T, Yan ZM, Zhuang J, Xiong AS (2022) Changes in carotenoid concentration and expression of carotenoid biosynthesis genes in *Daucus Carota* taproots in response to increased salinity. Horticulturae 8:650. https://doi.org/10.3390/horticulturae8070650