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Research Article

The mixture compost, vivianite and pyroclastite powders: Better organo-mineral fertilizer to stimulate the biosynthesis of nutrient elements of maize (*Zea mays* L.)

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Abstract

This study evaluated the effect of combining various natural fertilizers on maize seeds for nutritional values. A randomized complete block experimental design with 16 treatments and 03 replications was used : unfertilized soil (T0), poultry litter-based compost (T1), goat dung-based compost (T2), cow dung-based compost (T3), vivianite (T4), pyroclastite (T5), cow dung-based compost + vivianite (T6), cow dung based-compost + pyroclastite (T7), goat dung-based compost + vivianite (T8), goat dung-based compost + pyroclastite (T9), poultry litter-based compost + vivianite (T10), poultry litter-based compost + pyroclastite (T11), cow dung-based compost + vivianite + pyroclastite (T12), goat dung-based compost + vivianite + pyroclastite (T13), poultry litter-based compost + vivianite + pyroclastite (T14) and chemical fertilizer (T15). Seeds physical characteristics, such as thickness and mass of 1000 seeds were assessed. Evaluated seeds chemical properties were: moisture, as well as starch, lipid, protein and vitamin E contents. The results showed that the average of 1000 seeds mass from T12 treated plants was 2.02 and 1.03 times higher than those from T0 and T15 treated plants, respectively. T10 treatment increased the starch content of maize seeds by 1.88% and 1.54 % compared to T0 and T15 treatments respectively. In conclusion, the mixture of compost, vivianite and pyroclastite powders is a better organo-mineral fertilizer to stimulate the biosynthesis of maize nutrient elements. The production and application at sowing of poultry litter compost mixed with vivianite and pyroclastite powders stimulated maize nutritional value and promoted the use of local materials in organic farming.

1. Introduction

Sustainable agriculture in Sub-Saharan Africa, particularly in the Guinean Savannah Zone of Cameroon, faces major challenges related to soil degradation, nutrient deficiencies and dependence on costly, inefficient chemical fertilizers [1]. Maize (*Zea mays* L.), a staple crop in the Adamawa region, often suffers from low productivity and reduced nutritional quality due to poor soil fertility, especially deficiencies in organic matter, and essential nutrients [2, 3]. Although chemical fertilizers are commonly used, they present economic and environmental drawbacks, including high cost, limited accessibility and potential for long-term degradation [4, 5]. Therefore, there is a growing need to develop locally sourced and sustainable fertilization strategies. Liu and Li demonstrated that soil fertility, as well as plant productivity, is increased with the use of organic fertilizers [6]. In this context, the present study aimed to improve maize productivity under the high Guinean Savannah climate of Adamawa-Cameroon by using compost enriched with vivianite and pyroclastite powders [7].

Compost has physicochemical and biological properties that improve soil structure [6, 8] and soil biodiversity through the contribution of microorganisms, combat mineral depletion, improve physicochemical properties and help reduce the need for industrial nitrogen fertilizers [9]. Nonetheless, compost alone may not meet the nutritional requirements of plants grown in deeply weathered tropical soils. Vivianite, an iron phosphate mineral, has been cited as a potential phosphorus source [10]. Its chemical formula is $Fe_2 (PO_4)_2{\cdot}8H_2O$. The positive effects of vivianite powder on crop yields have been documented [8, 10]. Several studies have shown that vivianite application has a significant impact on phosphorus and nitrogen uptake and crop yields, thus bringing remarkable benefits to farming systems [5, 7]. Phosphorus is one of the essential macronutrients and a key element required for the proper physiological processes for plants. It is considered the second most importance macroelement after nitrogen [11]. Pyroclastites are defined as rocks rich in exchangeable bases, such as K^+, Ca^{2+}, and Mg^{2+}, which are beneficial to soil chemical properties [12]. Furthermore, pyroclastites- fragmented volcanic rocks rich in minerals [12] are of great interest to soil scientists as natural amendments for soil improvement due to their potential to increase soil fertility. Their natural macro and micronutrient enrichment suggests they may improve plant nutrition. However, no studies have been carried out on the nutritional value of maize grown in the High Guinean Savannah climate of Adamawa-Cameroon using compost enriched with vivianite and pyroclastite powders. This lack of data appears to be a handicap for the evaluation of this combination of natural fertilizers for improving the maize nutritional value. Previous studies have shown a significant effect of agricultural practices on the nutritional value of maize [13-15]. Maize is rich in starch (around 70%), fat, protein, ash, mineral elements (potassium, magnesium and phosphorus) and crude fiber [16]. Proteins, lipids, and vitamin E are essential for good nutrition in both humans and animals. Therefore, this study aimed to improve the physico-chemical properties of maize seeds through improving soil fertility by using organo-mineral fertilizers-based compost, vivianite and pyroclastite powders.

2. Materials and methods

2.1. Maize seeds and their origin

Seeds of the Shaba variety of maize were used in this study (Fig. 1). These seeds were harvested in the experimental farm of the Laboratory of Biodiversity and Sustainable Development of the University of Ngaoundere (Cameroon) during the 2023 and 2024 cropping seasons. The maize growing soil was acidic (pH = 5.00) and presented a clay textural class characterized by 43% of clay, 26% of silt and 31% of sand. The total nitrogen (N) content of the cropped soil was 0.12 %. The available phosphorus (mg/kg), potassium (K), calcium (Ca) and magnesium (Mg) contents (mg/100 g of dry growing soil) were 9.42, 1.96, 140.76 and 54.74 respectively [7]. This maize variety was chosen for its great adaptability to the rainy season, early germination, and short reproducti ve cycle (100 and 120 days). Varieties with a short reproduction cycle are advantageous for farmers because they may have several harvests per year if they have the possibility to practice off-season cropping [17].

Figure 1. Seeds of the SHABA variety of *Zea mays* L.

The seeds were first cleaned by hand picking to discard the damaged ones, packaged, and stored for physico-chemical analysis. Regarding field study, a randomized complete block experimental design with 16 treatments and 03 replications was used. The seeds used in this study were harvested from the maize plants subjected to the following treatments: unfertilized soil (T0), 500 g of compost derived poultry litter (T1), 500 g of compost derived goat dung manure (T2), 500 g of compost derived cow dung

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manure (T3), 10 g of vivianite powder (T4), 10 g of pyroclastite powder (T5), 500 g of compost derived cow dung manure + 10 g of vivianite powder (T6), 500 g of compost derived cow dung manure + 10 g of pyroclastite powder (T7), 500 g of compost derived goat dung manure + 10 g of vivianite powder (T8), 500 g of compost derived goat dung manure + 10 g of pyroclastite powder (T9), 500 g of compost derived poultry litter + 10 g of vivianite powder (T10), 500 g of compost derived poultry litter +10 g of pyroclastite powder (T11), 500 g of compost derived cow dung manure + 10 g of vivianite powder + 10 g of pyroclastite powder (T12), 500 g of compost derived goat dung manure + 10 g of vivianite powder + 10 g of pyroclastite powder (T13), 500 g of compost derived poultry litter + 10 g of vivianite powder + 10 g of pyroclastite powder (T14), 10 g of chemical fertilizers (NPK (20-10-10) + 5 g of urea 46%N) (T15). Two plants were consecutive in an elementary plot, spaced 50 cm apart. Compost and rock powder were applied per hole at time of sowing. NPK (20-10-10) chemical fertilizer and urea (46% N) were applied to the base of plants, respectively, at 15 days after plant emergence and at flowering. The raw organic materials for composting (poultry litter, cow dung and goat droppings) were collected from livestock facilities located near the University of Ngaoundere. Composting was conducted following the methodology outlined by [4], over a period of four months.

Vivianite samples were collected from the Hangloa Basin, located between 7°20' - 7°30' N latitude and 13°20' - 13°25' longitude. Chemical analyses of the powdered vivianite revealed a composition of Fe_2O_3 (68.72%), P_2O_5 (9.17%), Al_2O_3 (7.72%), and SiO_2 (9.67%). The total phosphorus content was estimated to be approximately 671.50 mg/kg with an assimilable phosphorus fraction of 81.13 mg/kg, indicating the potential for phosphate solubilization from this mineral source.

Additionally, pyroclastic rocks were sampled near Lake Tyson in the Adamawa region of Cameroon (7°15' N, 13°34' E). Their geochemical profile, comparable to that of the Tombel graben, showed high levels of essential agronomic bases, including CaO (> 8%), MgO (> 6%) and K_2O (> 1%) [12].

The chemical fertilizers used in this study were purchased from the local market in Ngaoundere. They included urea (46% N) and NPK formulation (20-10-10), indicating respective contents of 20% nitrogen, 10% phosphorus (as P_2O_5) and 10% potassium (as K_2O).

2.2. Determination of physical characteristics of maize seeds

The physical properties of maize seeds, specifically seed thickness and mass of 1000 seeds, were analyzed. Seed mass was measured using an electronic balance (SF-400) with a sensitivity of 1g after counting 1000 seeds. Seed thickness was assessed using a caliper gauge with a resolution of 0.1 mm.

2.3. Evaluation of chemical properties of maize seeds

2.3.1. Determination of moisture content

The moisture content was estimated following the standard oven-drying method. This method is gravimetric in nature and relies on the quantification of weight changes due to evaporation from heating. A representative seed sample (10 g) was precisely measured, and placed in a ventilated oven set at 105 °C for 24 h. Afterwards, the samples were cooled in a desiccator before weighing to avoid moisture absorption. The moisture content was determined using the following formula:

$$\text{Moisture content} = \frac{\text{Weight loss of sample}}{\text{Weight of the original sample}} \text{ X } 100$$

2.3.2. Determination of starch

Using the method of Jarvis et al. [18], total starch (amylose and amylopectin) was determined. The filtrate obtained after alkaline and acid hydrolysis was treated with iodine solution and absorbance readings were taken at 580 nm. The starch content was determined using standard curve with values ranging from 0 to 100 µg/mL.

2.3.3. Determination of total lipids

In accordance to AOAC [19], the total lipids were extracted with 100% hexane for 24 h. The samples were oven-dried at 60 °C and weighed before and after extraction. Lipid content was calculated as g of lipids per 100 g of dry matter (g/100 g DM), based on three replicate analyses.

2.3.4. Determination of total protein

Total protein was determined by Devani et al. [20]

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Table 1. Seeds physical characteristics of maize according to treatments and experimentation year.

Treatments	2023 Cropping season		2024 Cropping season	
	M1000S (g)	**TH (mm)**	**M1000S(g)**	**TH (mm)**
T0	199.33±5.13^{a}	3.58±0.16^{a}	231.66±5.86^{a}	4.44±0.19^{a}
T1	282.00±4.58^{g}	4.25±0.20^{e}	243.00±5.29^{b}	4.47±0.20^{a}
T2	220.33±5.51^{b}	3.92±0.18^{b}c	342.00±4.00^{g}	5.13±0.18^{d}e
T3	291.67±5.03^{g}	4.43±0.24^{f}	269.33±5.13^{d}	4.89±0.17^{c}
T4	261.67±3.51^{ef}	4.12±0.16^{d}e	303.33±1.15^{e}	5.10±0.24^{d}
T5	246.00±7.94^{cd}	4.01±0.21^{c}d	257.00±1.00^{h}	5.15±0.17^{d}e
T6	241.00±3.61^{c}	3.92±0.21^{b}c	313.00±5.29^{f}	5.04±0.23^{c}d
T7	266.67±7.64^{f}	4.09±0.16^{d}	438.00±1.00^{ij}	5.27±0.23^{e}
T8	207.67±8.08^{a}	3.77±0.20^{b}	240.00±7.00^{b}	4.63±0.22^{b}
T9	291.33±5.86^{g}	4.57±0.24^{f}g	440.67±1.53^{j}	5.59±0.21^{f}
T10	264.00±4.58^{ef}	4.15±0.14^{d}e	298.00±3.00^{e}	5.09±0.13^{d}
T11	253.33±12.22^{de}	4.09±0.19^{d}	253.00±5.00^{c}	4.53±0.16^{a}b
T12	365.33±9.07^{i}	5.17±0.28^{h}	467.33±3.51^{l}	6.07±0.25^{h}
T13	331.67±11.59^{h}	4.69±0.23^{g}	433.67±3.21^{i}	5.19±0.16^{d}e
T14	334.33±6.51^{h}	4.69±0.17^{g}	443.33±4.51^{j}	5.84±0.22^{g}
T15	379.00±2.00^{j}	5.83±0.26^{i}	452.33±4.04^{k}	6.00±0.28^{h}

M1000S: Mass of 1000 seeds, TH: Thickness, T0: unfertilized soil, T1: poultry litter-based compost, T2: goat dung-based compost, T3: cow dung-based compost, T4: vivianite, T5: pyroclastite, T6: cow dung-based compost + vivianite, T7: cow dung based-compost + pyroclastite, T8: goat dung-based compost + vivianite, T9: goat dung-based compost + pyroclastite, T10: poultry litter-based compost + vivianite, T11: poultry litter-based compost + pyroclastite, T12: cow dung-based compost + vivianite + pyroclastite, T13: goat dung-based compost + vivianite + pyroclastite, T14: poultry litter-based compost + vivianite + pyroclastite, T15: chemical fertilizer . Values of columns affected by the same letter are not significantly different.

using the Kjeldahl method [21]. Assessment of nitrogen was assessed using 412 nm colorimetric methods and converted to protein using a 6.25 factor. Results from three replicates were expressed in mg of total protein per gram of dry matter (mg/g DM).

2.3.5. Determination of Vitamin E

Vitamin E was determined according to Prieto et al. [22] with slight modifications. To a volume of 40 µL of sample, 80 µL of chromogenic reagent was added and kept in the dark for ten minutes. The samples were agitated at 37 °C for 90 min. Absorbance was measured at 695 nm. The results were provided in terms of α-tocopherol equivalent per hundred grams of dry matter as TcoE; thus, this value is expressed as mg/kg DM. These values were based on four replicates.

2.4. Statistical analysis

The collected data were subjected to analysis of variance (ANOVA). When statistically significant differences were detected ($p < 0.05$), Duncan's multiple range test was applied to compare the means. All statistical analyses were conducted using the Statgraphic Plus Program version 5.0.

3. Results and discussion

3.1. Maize seeds physical characteristics

The physical characteristics taken into account were the mass and thickness of the seeds. The masses and thickness of maize seeds, seeds are presented in Table 1 according to the fertilizer and cropping season. Analysis of variance (ANOVA) showed a highly significant difference ($P < 0.001$) between the treatments on the seed's physical characteristics.

1000 seeds mass ranged from 199.33 ± 5.13 g for harvested seeds from the unfertilized plot (T0) in 2023 to 467.33 ± 3.51 g for seeds from the amended plot with compost enriched with vivianite and pyroclastite powders (T12). Harvested seeds from the T12 treatment were heavier than those from all other treatments and were approximately 2.02 and 1.03 times heavier than seeds from the untreated plot (T0) and treated plot by chemical fertilizer (T15), respectively in the 2024 cropping season. These results recorded on seeds mass for T12 fertilizer are higher

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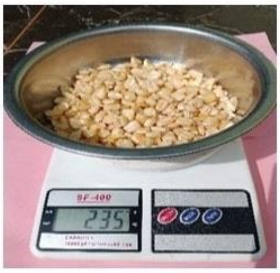
than the ranges reported in several studies. For instance, [23] studied the physicochemical and nutritional quality evaluation of maize varieties in Ethiopia and reported that the 1000 seed masses ranged from 287.40 to 354.86 g. The similar report [24] indicated 1000 seed masses ranging from 229 g to 242 g depending on the fertilizer.

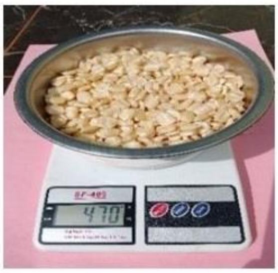
Seed mass is a key indicator of yield quality. A higher seed mass reflects greater accumulation of organic matter by the plant [25, 26]. Fig. 2 illustrates the mass values of maize seeds harvested in the T0, T12 and T15 treatments.

The thinnest seed thickness (3.58 ± 0.16 mm) was observed in harvested seeds from the T0 plot during the 2023 cropping season. Also, the thickest thickness (6.07±0.25 mm) was observed in harvested seeds from the T12 treatment during the 2024 crop season. The average thickness of seeds harvested from the T12 treatment was 1.37 times thicker than that from the unfertilized plot in 2024. Our results on seed thickness are higher than those of in their study [27] of the physical properties of maize, who reported that maize seed thickness varies from 4.22 to 5.55 mm. Fig. 3 illustrates the thickness values of harvested seeds for the T0, T12 and T15 treatments.

Maize seed thickness is an important measure of both physical quality and processing potential. It affects product yield, the precision of mechanical sorting, and how efficiently the seeds can be dried and stored [28]. It is often correlated with parameters like seed weight, density and nutrient content, making it a valuable indicator for varietal evaluation and genetic selection [29].



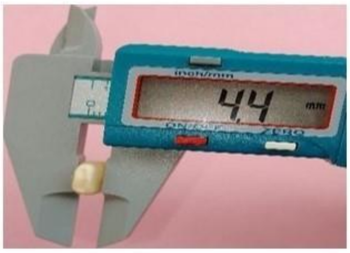
2a. Seeds from T0



2b. Seed from T12

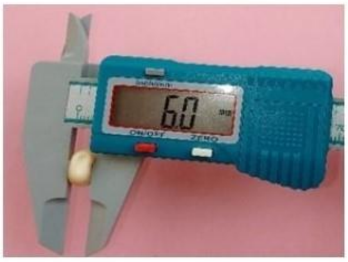
2c. Seed from T15

Figure 2. Mass of seeds from unfertilized soil (2a), treated plants with compost enriched with vivianite and pyroclastites powders (2b) and treated plants with chemical fertilizers (2c) in 2024 cropping season.



3a. Seed from T0

3b. Seed from T12



3c. Seed from T15

Figure 3. Thickness of seed from unfertilized soil (3a), treated plants with enriched compost with vivianite and pyroclastites powders (3b) and treated plants with chemical fertilizers (3c) in 2024 cropping season.

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Table 2. Moisture and starch content of the maize seeds according to the treatments and the year of experimentation.

Treatments	Moisture (%)		Starch (%)	
	2023	2024	2023	2024
T0	12.60±0.28^{ef}	13.06±0.34^{ef}	61.42±0.01^{a}	64.14±0.01^{b}
T1	14.00±0.14^{j}	14.26±0.16^{j}	63.75±0.06^{k}	64.06±0.00^{b}
T2	13.30±0.17^{gh}	12.96±0.13^{gh}	62.04±0.01^{b}	64.39±0.03^{de}
T3	12.00±0.15^{bc}	12.26±0.15^{bc}	63.71±0.02^{k}	65.11±0.00^{h}
T4	12.10±0.28^{c}	12.44±0.22^{c}	62.57±0.02^{f}	63.84±0.01^{a}
T5	12.50±0.11^{de}	12.70±0.09^{de}	62.05±0.00^{b}	64.66±0.1^{fg}
T6	11.80±0.12^{a}	12.00±0.08^{a}	63.15±0.02^{h}	64.26±0.01^{cd}
T7	12.00±0.11^{bc}	12.20±0.09^{bc}	62.56±0.01^{f}	64.63±0.10^{f}
T8	13.50±0.12^{i}	13.70±0.08^{i}	62.42±0.02^{e}	64.77±0.02^{g}
T9	13.20±0.10^{h}	13.40±0.10^{h}	63.15±0.01^{h}	64.32±0.02^{d}
T10	14.10±0.15^{j}	13.96±0.15^{j}	63.33±0.01^{i}	65.56±0.07^{i}
T11	12.80±0.14^{fg}	13.14±0.16^{fg}	62.19±0.03^{c}	64.15±0.01^{bc}
T12	11.80±0.11^{b}	12.00±0.10^{b}	63.42±0.01^{j}	65.06±0.02h
T13	12.70±0.17^{d}	12.44±0.13^{d}	62.70±0.00^{g}	64.14±0.01^{b}
T14	13.00±0.10^{fg}	12.80±0.11^{fg}	62.32±0.02^{d}	64.32±0.01^{d}
T15	14.10±0.24^{j}	14.44±0.17^{j}	62.46±0.02^{e}	64.46±0.01^{e}

T0: unfertilized soil, T1: poultry litter-based compost, T2: goat dung-based compost, T3: cow dung-based compost, T4: vivianite, T5: pyroclastite, T6: cow dung-based compost + vivianite, T7: cow dung based-compost + pyroclastite, T8: goat dung-based compost + vivianite, T9: goat dung-based compost + pyroclastite, T10: poultry litter-based compost + vivianite, T11: poultry litter-based compost + pyroclastite, T12: cow dung-based compost + vivianite + pyroclastite, T13: goat dung-based compost + vivianite + pyroclastite, T14: poultry litter-based compost + vivianite + pyroclastite, T15: chemical fertilizer . Values of columns affected by the same letter are not significantly different.

3.2. Chemical properties of maize seeds

The studied chemical properties of maize seeds included moisture, starch, lipid, protein, and vitamin E contents (Table 2). Statistical analysis (ANOVA) indicated that fertilizer application significantly increased the nutrient composition of maize seeds ($p < 0.001$).

3.2.1. Moisture content

The highest seed moisture content (14.27 ± 0.21%) was observed in the harvested seeds from plots treated by chemical fertilizer (T15) and the lowest moisture levels (11.60 ± 0.10% and 11.90 ± 0.10%) were recorded on seeds harvested from treated plots by compost enriched with vivianite powder (T6), and by compost enriched with vivianite and pyroclastite powders (T12). The moisture content of seeds from T15 fertilizer was 1.11 times higher than those from the unfertilized plots and 1.20 times higher than that of the seeds from T12. These results on seeds moisture contents are similar to those of [16], who studied the varietal diversity, quality and use of maize in West Africa and revealed that the seed moisture contents of maize ranged from 11.1 % to 14.1%, depending on variety.

This finding indicates that synthetic nitrogen-rich fertilization (T15) caused the crops to continue vegetative growth for a longer period of time while delaying leaf senescence, thereby reducing the rate of dormancy to grain dehydration. This finding corroborates previous studies that have shown that high amounts of nitrogen can maintain green leaf area for longer periods of time, which can extend the duration of the grain-filling phase [30, 31]. Nonetheless, these high moisture levels could also be problematic when attempting to store grain, as this could lead to a greater likelihood of fungal growth and reduced shelf-life [32]. However, it seemed like T6 and T12 treatments encouraged greater grain desiccation as a more moderated nutrient release was enabled. Geological fertilizers are known to be slow release as in the case of phosphate and potassium-rich powders while reducing excessive vegetative growth and promoting timely senescence [33, 34]. This balance produced a more synchronized maturation at the end of the growing season allowing for more quick grain drying. Thus, organomineral blends provide a

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favorable supply of nutrients and prevent over-stimulating vegetative growth late in the season. In regard to post-harvest management and grain preservation, moisture content that is lower is more desirable because it would result in lower drying and storage costs, which can be lost through moisture.

3.2.2. Starch content

The lowest starch content (61.42 ± 0.01%) was recorded in seeds harvested from the control plot that was not treated (T0) in 2023, whereas the highest contents (65.06 ± 0.02% and 65.56 ± 0.07%) were recorded in the seeds harvested from T12 (compost derived cow dung manure + vivianite powder + pyroclastite powder) and T10 treatments in 2024. Overall, the starch content in seeds treated with T10 was 1.02 times higher than that in the control seeds in 2024. The starch content of seeds from unfertilized soil in 2024 was 1.04 times greater than that of the same plants in 2023. These results on starch content of seeds are similar to those of [35], who studied the quality protein maize inbred lines for improved nutritional value of maize in Southern Africa and revealed that the starch content of maize varieties ranged from 61% to 67%. Furthermore, the report [23], on the physicochemical and nutritional quality of maize varieties in Ethiopia and found that the starch content of maize varieties ranged from 67.91% to 69.97%. Starch in maize seeds serves as both an important staple food and source of animal feed. Starch, the dominant component of the grain's dry weight, serves as a major energy source in both human and animal diets [36]. The structure of starch, which is composed of amylose and amylopectin, directly affects its digestibility and usefulness for industrial applications, such as ethanol or modified starch production [37].

3.2.3. Protein and lipid content

The highest values of protein content (9.79 ± 0.01 mg/g and 9.65 ± 0.02 mg/g) were recorded in the harvested seeds on T1 (compost derived poultry litter) and T12 (compost derived cow dung manure + vivianite powder + pyroclastite powder) treatments during 2023, and the lowest values (8.53 ± 0.01 mg/g and 8.57 ± 0.01 mg/g) were recorded in seeds from T13 (compost derived goat dung manure + vivianite powder + pyroclastite powder) and T0 (unfertilized soil) during the 2024 cropping season (Table 3). T1 plot seeds averaged 1.07 and 1.05 times more protein than those from unfertilized soil and chemical fertilizer, respectively, in the 2023 cropping season. The protein content of seeds from unfertilized soil in 2023 was 1.07 higher than that from the same plants in 2024. The Protein content of the maize seeds observed in this study was nearly in accordance with the findings [23], who revealed that the protein contents of three maize varieties were in the range of 9.05 to 9.87% with an average value of 9.41% and with the report [38], who reported maize protein content ranging between 9.31 and 13.60%. However, the average protein contents were also reported [39, 40] reported as 6.63% and 6.66%, respectively, while Duman et al. [41] reported the maize protein content was ranged from 7.45 to 13.66%. Proteins are more than just a source of energy; they play a key role in growth, tissue repair, and immune function. Getting the right amount is crucial, as both too little and too much can negatively affect metabolic health [42, 43]. Lipid content varied from 3.38 ± 0.01mg/g for the harvested seeds on T0 plants in 2024 to 4.64 ± 0.02 mg/g for seeds treated with T12 in the 2023 cropping season (Table 3). T12 plot seeds averaged 1.37 times more lipids than T0 plot seeds. The average lipid content of seeds from unfertilized soil in the first cropping season was 1.23 times greater than that of the same plants in the second cropping season. The data obtained on the lipid content of maize seeds in this work partially corroborate those reported by Amegbor et al. [35] who revealed that the mean lipid content of this maize was 4.52%. The similar report [44] was an average of 4.47% of maize lipid.

Maize lipids contain a high amount of essential fatty acids. It helps maintain low cholesterol levels in the blood, which reduces the risk of heart disease and supports cardiovascular health, brain development, and immune defenses [45-47].

3.2.4. Vitamin E content

The least Vitamin E content (17.44 ± 0.01 mg /Kg) was recorded in the harvested seeds on the control plot that was not treated (T0) in 2023, whereas the highest content (19.77 ± 0.01 mg /Kg) was recorded in seeds harvested on the T12 treatment in 2024 (Table 4). Vitamin E content of seeds from T12 fertilizer is 1.03 and 1.01 times higher than that from unfertilized soil

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Table 3. Protein and lipid content of the maize seeds according to the fertilizers and the year of experimentation.

Treatments	Protein content (mg/g)		Lipid content (mg/g)	
	2023	2024	2023	2024
T0	9.14±0.02[a]	8.57±0.01[b]	4.15±0.02[b]	3.38±0.01[a]
T1	9.79±0.01[h]	8.94±0.01[h]	4.36±0.02[g]	3.81±0.01[g]
T2	9.54±0.00[f]	8.67±0.00[c]	4.27±0.01[e]	3.98±0.00[j]
T3	9.22±0.01[b]	8.85±0.00[f]	4.36±0.00[g]	3.93±0.00[i]
T4	9.55±0.00[f]	8.74±0.01[d]	4.33±0.01[f]	3.87±0.01[h]
T5	9.36±0.01[d]	8.92±0.00[h]	4.04±0.01[a]	3.42±0.02[b]
T6	9.63±0.01[g]	8.85±0.01[fg]	4.06±0.01[a]	3.44±0.01[b]
T7	9.44±0.01[e]	8.79±0.02[e]	4.22±0.01[d]	3.49±0.00[c]
T8	9.26±0.02[c]	8.98±0.00[i]	4.41±0.01[h]	3.65±0.01[e]
T9	9.245±0.03[bc]	8.66±0.01[c]	4.19±0.01[c]	3.74±0.01[f]
T10	9.55±0.01[f]	9.06±0.02[j]	4.21±0.00[cd]	3.63±0.01[e]
T11	9.41±0.02[e]	9.12±0.00[k]	4.44±0.01[h]	3.72±0.01[f]
T12	9.65±0.02[g]	9.38±0.01[l]	4.64±0.02[i]	4.47±0.01[k]
T13	9.17±0.01[a]	8.53±0.01[a]	4.43±0.01[h]	3.56±0.01[d]
T14	9.42±0.01[e]	8.77±0.01[e]	4.23±0.02[d]	3.73±0.00[f]
T15	9.34±0.01[d]	8.87±0.01[g]	4.34±0.01[fg]	3.65±0.02[e]

T0: unfertilized soil, T1: poultry litter-based compost, T2: goat dung-based compost, T3: cow dung-based compost, T4: vivianite, T5: pyroclastite, T6: cow dung-based compost + vivianite, T7: cow dung based-compost + pyroclastite, T8: goat dung-based compost + vivianite, T9: goat dung-based compost + pyroclastite, T10: poultry litter-based compost + vivianite, T11: poultry litter-based compost + pyroclastite, T12: cow dung-based compost + vivianite + pyroclastite, T13: goat dung-based compost + vivianite + pyroclastite, T14: poultry litter-based compost + vivianite + pyroclastite, T15: chemical fertilizer . Values of columns affected by the same letter are not significantly different.

and chemical fertilizer respectively in 2024. The Vitamin E content of seeds from unfertilized soil in 2024 is 1.10 times greater than that of the same plants in 2023. Vitamin E, acts as a powerful antioxidant. It protects cells from oxidative stress, supports immune function, and-improves the quality of animal products, especially in modern farming systems [48, 49]. Maize biofortification, which involves breeding crops to enhance their nutrient content like β-carotene and vitamin E, has proven to be an effective way to combat hidden hunger in populations that rely heavily on maize [50].

The application of various natural fertilizers in this study demonstrated significant positive effects on the physiological parameters and seed yield of maize. A significant finding is that these improvements in plant growth and physiology translated directly into better grain nutritional quality, particularly the accumulation of starch, proteins, healthy fats, and vitamin E [7, 51-53]. The underlying mechanisms of these benefits are multi-faceted. The composts used were rich in organic matter and helped balance the soil's acidity [54]. This created a thriving environment for beneficial microbes. This enhanced microbial activity is crucial for nutrient mineralization, increasing the bioavailability of essential elements like phosphorus [55]. Phosphorus plays a fundamental role in photosynthesis, and its improved uptake boosts the production of photoassimilates (sugars) [7, 56, 51]. These sugars are subsequently translocated to the developing grains and serve as the primary carbon skeletons for the synthesis of starch (the main energy reserve) and are involved in pathways leading to lipid and protein accumulation [53].

The optimum treatment, T12 (cow dung compost enriched with vivianite and pyroclastite powders), was successful not only because of the addition of more nutrients but also because of the creation of the right balance of nutrients.

This balance prevented antagonistic effects, such as the inhibition of potassium (K) and ammonium (NH_4^+) uptake by other cations [57- 59]. An optimal potassium status is vital for enzyme activation and the efficient transport of sugars to the grain, directly

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Table 4. Vitamin E content (mg/Kg) of maize seeds depending on fertilizers and study year.

Treatments	Study years		Treatments	Study years	
	2023	2024		2023	2024
T0	17.44±0.01[a]	19.21±0.01[b]	T8	17.85±0.02[e]	19.45±0.02[d]
T1	17.76±0.02[d]	19.26±0.00[c]	T9	18.16±0.01[f]	19.60±0.01[f]
T2	17.49±0.01[b]	19.12±0.01[a]	T10	18.21±0.01[g]	19.84±0.01[j]
T3	17.55±0.01[c]	19.45±0.00[d]	T11	18.13±0.01[f]	19.66±0.01[g]
T4	17.52±0.00[b]	19.46±0.01[d]	T12	18.22±0.01[g]	19.77±0.01[i]
T5	17.73±00[d]	19.86±0.03[k]	T13	18.15±0.02[f]	19.50±0.02[e]
T6	19.25±0.02[j]	19.46±0.00[d]	T14	19.01±0.00[h]	19.71±0.01[h]
T7	19.40±0.00[k]	19.26±0.01[c]	T15	19.08±0.03[i]	19.60±0.01[f]

T0: unfertilized soil, T1: poultry litter-based compost, T2: goat dung-based compost, T3: cow dung-based compost, T4: vivianite, T5: pyroclastite, T6: cow dung-based compost + vivianite, T7: cow dung based-compost + pyroclastite, T8: goat dung-based compost + vivianite, T9: goat dung-based compost + pyroclastite, T10: poultry litter-based compost + vivianite, T11: poultry litter-based compost + pyroclastite, T12: cow dung-based compost + vivianite + pyroclastite, T13: goat dung-based compost + vivianite + pyroclastite, T14: poultry litter-based compost + vivianite + pyroclastite, T15: chemical fertilizer . Values of columns affected by the same letter are not significantly different.

influencing starch deposition and potentially the concentration of antioxidants like vitamin E. Concurrently, a balanced and steady supply of nitrogen (critical for the synthesis of amino acids and proteins) was likely achieved without the luxury consumption or imbalances caused by the over-rich poultry and goat composts [7, 60].

The significant variation in yield and nutritional parameters from 2023 to 2024 underscores the profound influence of climatic conditions. Water stress (both deficit and waterlogging) and temperatures exceeding 30°C during the critical grain-filling period are major abiotic stressors [61, 62]. They disrupt photosynthetic efficiency and accelerate senescence, severely shortening grain-filling duration. This not only reduces grain size and yield but also compromises the metabolic processes responsible for reserving starch, protein, and lipid levels [61,62]. Consequently, under such stress, the nutritional density and overall quality of the harvest are diminished, highlighting the complex interaction between soil management and climate in determining the final grain quality.

4. Conclusions

The physicochemical properties of maize seeds vary depending on the growing substrate. The seed weights from the treated plots with 500 g of compost derived cow dung manure + 10 g of vivianite powder + 10 g of pyroclastite powder (T12) were 2.02 and 1.03 times heavier than those from the untreated plot (T0) and treated chemical fertilizer plots (T15), respectively. The thickness of seeds from T12 fertilizer was roughly 1.37 times thicker than those from T0 plants. The moisture content of harvested seeds on T15 fertilizer was 1.11 times higher than that of T0 seeds and 1.20 times higher than that of seeds from T12 plants. Seeds from T12 fertilizer were 1.03 and 1.02 times richer in starch compared to T0 and T15 treatments, respectively. T12 fertilizer increased the maize seed protein contents by 5.58 % and 3.32 % compared to T0 and T15 respectively. The seed lipid contents of T12 plants were 1.12 times and 1.07 times higher than that of seeds from T0 and T15 plants, respectively. T12 fertilizer increased the vitamin E content by 4.28 % when compared with the control. The mixture of compost, vivianite and pyroclastite powders is a better organo-mineral fertilizer to stimulate the biosynthesis of maize nutrient elements. Production and application of a formulation consisting of compost derived cow dung manure, vivianite and pyroclastite powders in a ratio (50, 1, 1) per plant at sowing time for maize growth, would not only increase the seed nutritional quality, but also confer value to our locally available material for organic agriculture.

Authors' contributions

Protocol writing and statistical analyses, C.M., L.T.T.; Field work and laboratory analyses, A.M.; Drafted the

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Availability of data and materials

All data will be made available on request according to the journal policy.

Conflicts of interest

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

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