

Formulation of Fertilizers from Theobroma Cacao Pods and Moringa Oleifera Leaves and Their Effects on Nutritive Quality of Eggplant *Solanum aethiopicum* Gilo

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Abstract

Declining soil fertility due to continuous cropping on smallholder farms, combined with the rising cost of imported chemical fertilizers, necessitates the search for local resources for soil fertility management. The objective of this study was to identify the most effective fertilizer—based on cocoa pod husks enriched with *Moringa* leaves—for boosting the accumulation of nutrients, minerals, and phenolic compounds in the fruit of the **Solanum aethiopicum** eggplant (Gilo N'Drowa variety). A randomized complete block design with three replicates was used. The experiment involved five organic fertilizer combinations (F1, F2, F3, F4, and F5) alongside a control (T0). Three increasing application rates were employed (1, 2, and 4 kg/m²). The trials were conducted over three cropping cycles. The chemical composition of the fertilizers was determined, as were the levels of dry matter, crude protein, total phenols, flavonoids, and minerals. Analysis results showed that adding *Moringa* leaves to cocoa pod husks increased the fertilizer's concentration of N, P, K, Ca, and Mg, thereby reducing the carbon-to-nitrogen (C/N) ratio. Increasing the proportion of *Moringa* leaves in the fertilizer mixture had a significant positive effect on the accumulation of protein, minerals, total phenols, and flavonoids in the fruit. The application rate did not have a uniform effect across all these parameters. The F4 mixture (25% cocoa pod husks and 75% *Moringa* leaves), which exhibited optimal characteristics (0.3% P, 5.5% K, 4% Ca, 0.5% Mg, and a C/N ratio of 21.4), resulted in the highest average levels of nutrients

and bioactive compounds in the fruit. Consequently, the partial substitution of cocoa pod husks with 75% *Moringa* leaves in fertilizers should be encouraged in order to enrich eggplant fruits with nutrients and bioactive compounds.

Keywords

Solanum aethiopicum Gilo, Organic Fertilizer, Cocoa Pods, Minerals, Moringa Leaves, Proteins, Dry Matter, Polyphenols

1. Introduction

African eggplant *Solanum aethiopicum* is an important vegetable for both rural and urban communities in Africa. The crop provided healthiest fruit with low calories, dietary fiber, and various vitamins and fundamental mineral elements, including potassium, calcium, magnesium, zinc, iron, for ensuring food and nutritional security [1]. Additionally, fruit contains polyphenols, including phenolic acids and flavonoid that are appreciated for antioxidants benefits [2] [3]. The edible groups of African eggplant (Gilo, Kumba and Shum) are adapted to diverse areas depending on agro climatic conditions. The Gilo group is commonly found in humid areas all over tropical Africa where its members grow best at the full sun on fairly deep and well-drained soils of pH 5.5 - 6.8, with 25°C - 35°C and 20°C - 27°C day and night temperatures, respectively [4]. The most popular variety “N’drowa” has noticeable qualities such mite-resistant, mild taste, a great yield potential, short harvesting time as well as high shelf life [4]. The production of eggplant N’drowa in the woodland savanna of West Africa is constrained by the low level of soil fertility, coupled with sometimes continuous use of synthetic fertilizers [1].

Soil fertility depletion and widespread nutrient deficiencies are matters of concern in tropical regions of the world. Worldwide farmers are highly dependent on high-cost chemical fertilizers as a source of plant nutrients. The skyrocketed price cost of synthetic fertilizers and issues about the impact of their long-term use on soil degradation and environmental pollution have led to a significant shift toward organic fertilizers. Organic farming and organic products are gaining momentum in the agricultural sector as they are widely promoted [5]. The intensive studies by researchers have reported that using organic fertilizer instead of chemical fertilizer can improve soil microbial community, physicochemical characteristics and improve the plant production quality [6]-[8]. Nevertheless, the capacity of organic fertilizers to supply nutrients for crops depends on plant, organic material and the agro climatic dominant conditions in the field for subsequent decomposition which limits the generalization of the results [9]. This local, low-cost, durable, environmentally friendly, and readily available material could be used to manage soil quality within sustainable and long-lasting agroecosystems.

Côte d’Ivoire is the world’s leading cocoa producer, with an estimated 2 to 2.2

million tonnes of cocoa beans for the 2025-2026 season, according to analysts from the Coffee and Cocoa Council (2026).

Toumbokro agro-industrial plantation in the district of Yamoussoukro (center of Côte d'Ivoire) generated a large amount of four types of co-products: cacao pod husk (CPH), placenta, cacao mucilage, and cacao bean shells (CS). The CPH represent about 70% - 75% of the whole fruit is locally used as organic fertilizers. This green fertilizer is a source of macro and micronutrients necessary to improve plants productivity, but are relatively poor in nitrogen [10] [11]. Unfortunately, fibrous materials, including lignin, cellulose, hemicellulose, and pectin which could retard the organic matter decomposition [12]. This situation is harmful for the restoration of the soil fertility and constitutes an important challenge.

Moringa (*Moringa oliefera*) is an Asian plant that lives in the tropics and spreads throughout Cote d'Ivoire. More recently, there has been increasing interest for the use of *Moringa* leaves in tropical agricultural systems [13]. The liquid extracted from moringa leaves has been used in agriculture to improve the growth and productivity of several crops. The efficacy of moringa leaf extract is attributed to its largest mineral and numerous plant growth hormone [13] [14].

The study reported herein aimed to study the effect of various Moringa leaves-enriched cocoa pods fertilization on the amount of dry mater, nutrient, minerals and phenolic compounds of *Solanum aethiopicum* Gilo N'Drowa fruits.

2. Material and Methods

2.1. Description of the Study Site

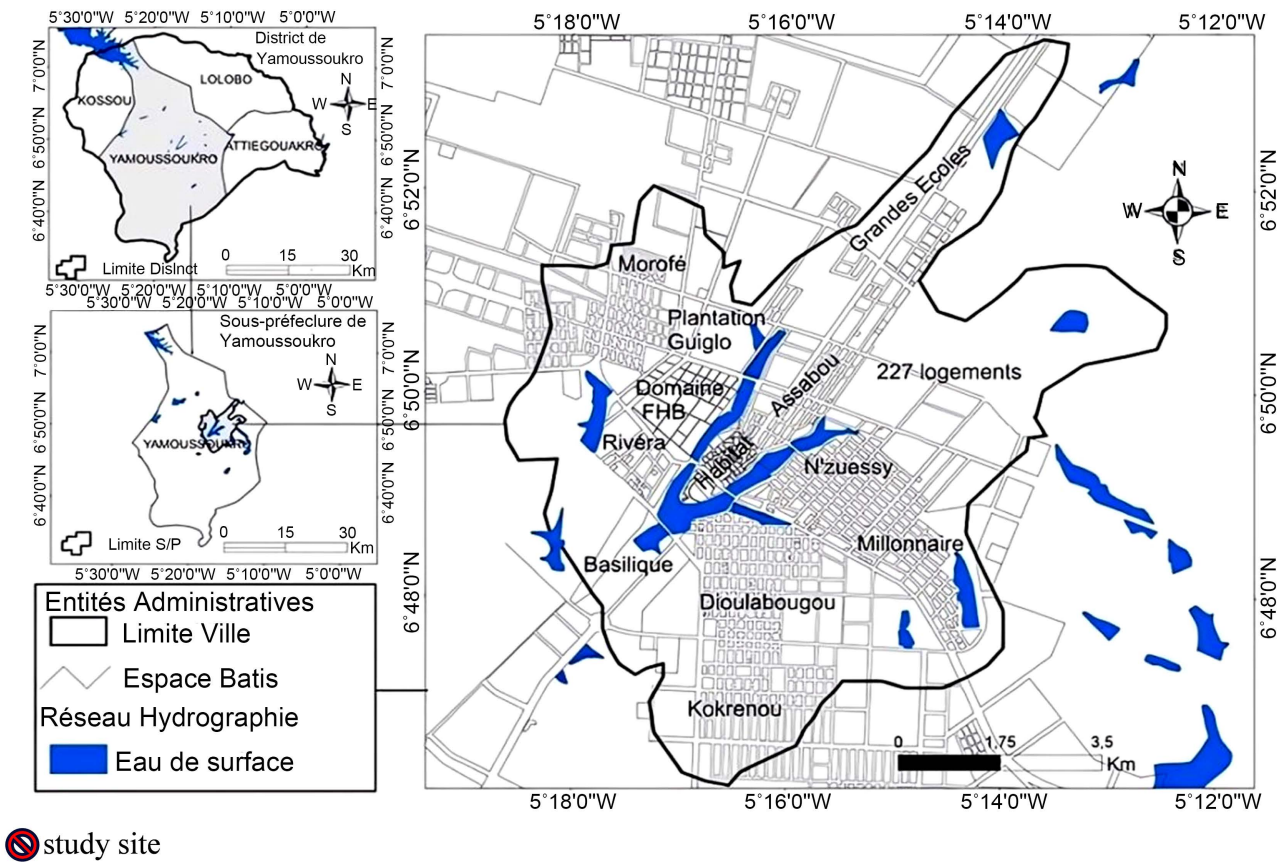
The experiment was conducted in Yamoussoukro (6.821°N, 5.277°W; altitude 214 m), the capital of Côte d'Ivoire (Figure 1). Located in the south-central part of the country, at the transition zone between savanna and forest, the city lies 216 km from Abidjan, the economic capital. Average annual precipitation in the area is 1,098 mm, following a bimodal pattern characterized by two rainy seasons (April to June and August to October) and two dry seasons (one in July and the other from November to March). The average daily temperature ranges from 31°C to 35°C during the day and from 19°C to 23°C at night (Figure 2). The average sunshine duration is 12.3 hours per day [15]. The trials took place from February 2025 to October 2026. The soil exhibited low organic carbon content (TOC = 1.02), a pH of 6.1, and a cation exchange capacity of 4.2 cmol/kg, with a sandy-clay texture (8.83% clay).

2.2. Plant Material

The experiment used the hybrid eggplant (*Solanum aethiopicum* Gilo) cultivar Ndrowa developed by CNRA, which is referenced Aub 21/06Du "Ndrowa" and was harvest between the 90th and 120th day after direct seeding.

Cocoa pod husks were collected from Toumbokro (5°22 N, 4°8 W) in the district of Yamoussoukro and were air-dried 7 days and grounded to pass through a 2 mm sieve.

The *Moringa oleifera* leaves were collected from Yamoussoukro under the trees and were air-dried 7 days, grounded then crushed and sieved ($\varnothing < 2\text{mm}$).



study site

Figure 1. Map showing the study area and the trial site.

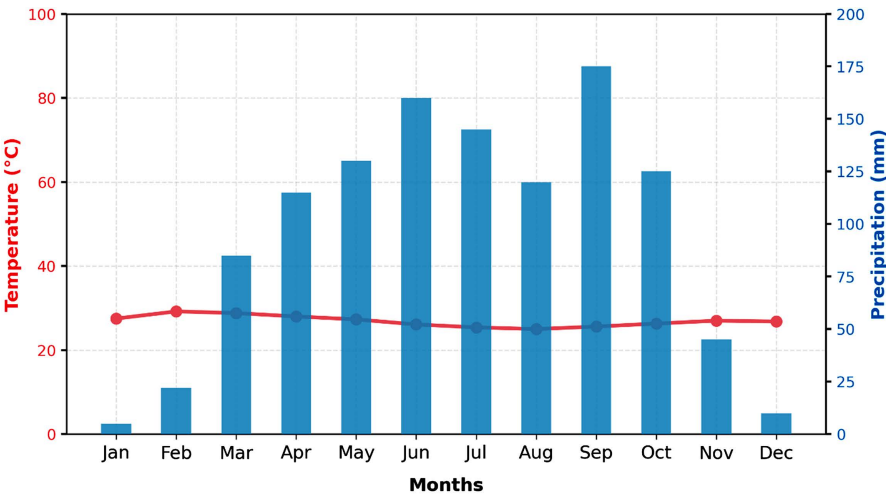


Figure 2. Yamoussoukro ombrothermic diagram 2025.

2.3. Chemicals and Reagents

The reagents used were of analytical quality, quercetin, Folin-Ciocalteu reagent,

were purchased from Sigma (St Louis, USA). Gallic acid, sodium carbonate and iron sulfate were obtained from Merck (Damstad, Germany), methanol, Tris-HCL, iron chloride from Pro labo (Briare, France). Sodium nitrate was obtained from Fluka laboratories. Aluminum trichloride was obtained from Panreac (Spain) and potassium iodate from Prolabo (Sion, Switzerland). Potassium chloride, Sodium acetate, Methanol, Sodium carbonate, Sodium hydroxide, Hydrochloric acid and acetone reagents were purchased from Merck (Damstad, Germany). Gallic acid, Sodium nitrite, Aluminum chloride, were purchased from Fisher Scientific (Pittsburgh, PA, USA). All other reagents were of analytical quality grade. The water used is produced by a Selecta L-4B bi-distiller at the Soil Health and Plant Nutrition Laboratory (LASSNP).

2.4. Experimental Set-Up and Procedure

Each large block received the various formulations at increasing application rates (1, 2, and 4 kg/m²). The trials were conducted using a randomized complete block design with three replicates for each of the five formulations (F1, F2, F3, F4, F5). The treatments compared were based on a two-component mixture (A and B), where the sum of the proportions always equaled 100%; thus, the percentage of the second component was determined by the percentage of the first. Each block included the following treatments:

- T0: absolute control (soil with no fertilizer application);
- F1: application of crushed cocoa pod husks only;
- F2: application of 75% crushed cocoa pod husks and 25% crushed Moringa leaves;
- F3: application of 50% crushed cocoa pod husks and 50% crushed Moringa leaves;
- F4: application of 25% crushed cocoa pod husks and 75% crushed Moringa leaves;
- F5: application of crushed Moringa leaves only.

A total of 54 experimental plots were maintained during the trial. Organic fertilizer doses were applied manually and incorporated into the soil to a depth of approximately 10 cm. Treatments were assigned to experimental units randomly (**Figure 3**).

Sowing was performed manually with a spacing of 80 cm between rows and 40 cm between plants (or planting holes) within the row (**Figure 1**). This geometric layout defines a growing area of 0.32 m² per planting station (0.80 m × 0.40 m), corresponding to a theoretical planting density of 31.25 plants per hectare (based on one plant per station after thinning). At the level of the individual plot, each unit comprises four crop rows with ten plants each, resulting in a total of 40 plants per plot. The two central rows (20 plants) served as the harvestable area for agronomic measurements, in order to eliminate edge effects.

2.5. Fruit Collection

At 98 and 106 days after planting, 1 kg of mature fruit was harvested from each

experimental plot (accounting for replicates); the fruit had reached near-maximum size but showed no change in epicarp color. The eggplants were transported to the laboratory, washed with tap water followed by distilled water, dried on absorbent paper, placed in clear plastic bags, and stored in opaque containers at 4 °C for subsequent analysis.

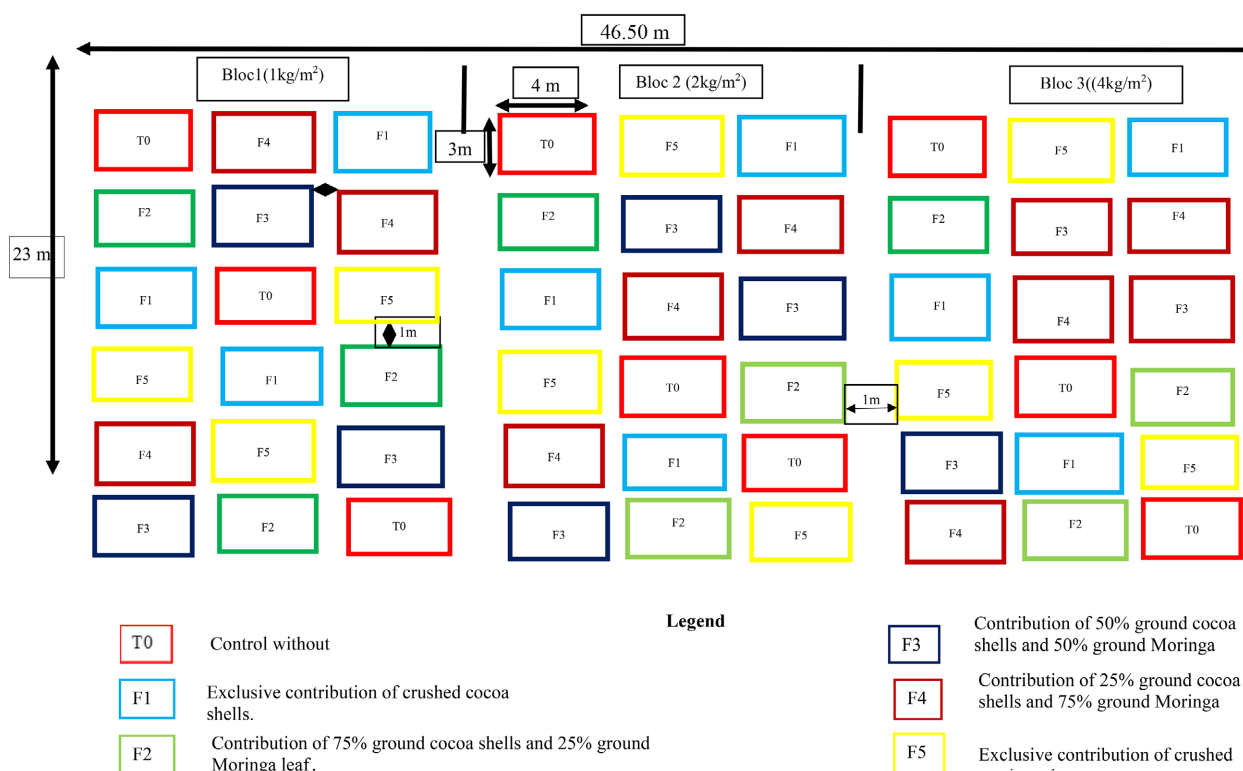


Figure 3. Distribution of formulations on the experimental plot.

2.6. Physico-Chemical Analysis

2.6.1. Determination of Organic Carbon

Total organic carbon (TOC) in the samples was determined by titration [16]. A 1 g sample portion was weighed into a 250 mL conical flask, and 10 mL of 1 N potassium dichromate was added and mixed thoroughly. A 20 mL volume of concentrated sulfuric acid was slowly added; the mixture was then shaken vigorously for 1 minute and allowed to stand for 30 minutes. A volume of 200 mL of demineralized water, 10 mL of concentrated phosphoric acid, and 10 to 15 drops of ferroin indicator solution were added. Following the reaction, the excess dichromate that had not reacted with the sample was titrated with 0.5 N ferrous iodate solution until a final brown color was reached. The percentage of carbon in the sample, expressed as % C, was determined as follows:

$$\text{COT}(\%) = \frac{(A - B) \times 10 \times 0.004 \times 100}{P \times A} \quad (1)$$

2.6.2. Determination of Cation Exchange Capacity (CEC or T)

Cation exchange capacity (CEC or T) was determined using a method developed

by [17], based on contacting an alcohol-washed soil sample with a sodium chloride (NaCl) solution of known concentration. Na⁺ ions displace the cations from the adsorption complex and bind to it. The solution collected during saturation contains the exchangeable cations, as well as ions quantified by the difference between the initial ion concentration and the concentration remaining after contact with the soil. Exchangeable cations were determined in the same extract used for the cation exchange capacity measurement. The extract was distilled using a Kjeldahl apparatus and then titrated with hydrochloric acid (HCl). Results were expressed in cmol/kg of soil.

2.6.3. Dry Matter

The moisture content and dry matter content were determined using AOAC Official Method [18] (by measuring 2 g of the sample into a previously weighed crucible). The porcelain crucible plus sample was transferred into the oven set at 105°C to dry to a constant weight. Regular weighing is carried out until the mass stabilizes, which reflects the evaporation of residual water from the sample. At the end of drying, the crucible plus sample was removed from the oven and transferred to the desiccator, cooled for ten minutes and weighed. The values obtained were subjected to Equations 1:

$$\text{Dry matter} = \frac{(W3 - W0)}{(W1 - W0)} \times 100 \quad (2)$$

where: $W0$ = weight of empty crucible, $W1$ = weight of crucible plus sample and $W3$ = weight of crucible plus oven-dried sample.

2.6.4. Nitrogen and Crude Protein

The nitrogen and crude protein of organic materials were determined according titrimetric method dosage after digestion by Kjeldahl procedures [19] with some modifications. About 1 g of plant tissues are placed in pyrex Folin-Wu tubes and digested with a salt-catalyst-sulfuric acid mixture by heating the tubes in an aluminum block. The catalyst consisting of copper sulfate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$), potassium sulfate (K_2SO_4) are added with diluted sulfuric acid and water. Samples are digested at the boiling point of the mixture for 60 min after initial clearing of the digests. The mineralized sample was transferred into a 100 mL flask and adjusted with distilled water. Ten mL of the mineralized sample solution was taken and then 10 mL of 40% NaOH was added and distilled for 10 min. The distillate was trapped in a flask containing 20 mL of sulfuric acid (H_2SO_4) in the presence of methylen bromocresol red color indicator. The content of the flask was titrated against 0.1 N NaOH until the solution became colorless. The total nitrogen content is determined by Equation (2). Crude protein was deduced by multiplying the percent total organic nitrogen (N) by a conversion factor of 6.25.

$$\text{Total N}(\%) = \frac{100V \times N \times 0.014}{P} \times 100 \quad (3)$$

where: V = volume (mL) of NaOH, P = weight of the sample, N = normality of

NaOH and 0.014: coefficient assigned to the concentration of the normal nitrogen solution (14/1000).

2.6.5. Organic Carbon and Organic Matter

Total organic carbon and organic matter of soil and fertilizer were determined [20]. About 1 g of sample is weighed into a 250 conical flask and 10 ml of 1N potassium dichromate is added and homogenized. A 20 mL volume of concentrated sulfuric acid is added slowly and then shaken vigorously for 1 minute and allowed to stand for 30 minutes. A volume of 200 mL of deionized water, 10 mL of concentrated phosphoric acid and 10 to 15 drops of the ferroin indicator solution are added. After the reaction, the excess of dichromate that did not react with the sample is titrated with 0.5 N ferrous sulfate solution to the final brown color. The percentage of carbon in the sample expressed as % C is determined by Equation (3) below: Organic matter was deduced by multiplying the percent total organic carbon (COT) by 1.72.

$$\text{COT}(\%) = \frac{10(A - B) \times 0.004}{P \times A} \times 100 \quad (4)$$

where: A = volume (mL) of ferrous sulfate used for the control, B = volume (mL) of ferrous sulfate used for the sample, P = weight (g) of the titrated sample expressed on dry basis, 0.004: number of g of C per ml of dichromate.

2.6.6. Phosphorus

Phosphorus content of fertilizers was determined by incinerating the samples in a muffle furnace at 550° and then determined by UV-visible colorimetry. Phosphorus present in its ortho-phosphate form, reacts with the vanadate-molybdate reagent to produce a yellow-orange complex, which absorbance is measured at a wavelength of 400 nm. The phosphorus content is then determined according to the standard calibration curve [21].

2.6.7. Mineral Composition

The determination of the mineral elements (K, Ca, Mg, Fe and Zn) of organic materials were carried out by atomic absorption to flame air-acetylene of type VARIAN AA20 after calcination at 550°C and recovery of the ashes with hydrochloric acid [22]. A quantity of 0.4 g of ground sample was weighed into a porcelain crucible and then placed in a furnace (PROLABO) at 650°C for 5 h. After cooling, 5mL of nitric acid 1 mol·L⁻¹ is added to the obtained ash and then evaporated on a sand bath. To the residue is added 5 mL of 0.1 mol·L⁻¹ is added to the residue and put back into the oven at 400°C for 30 min. The final residue is recovered with 10 ml of hydrochloric acid 1 mol·L⁻¹ hydrochloric acid and poured into a 50 mL flask. The crucible is rinsed twice with 10 mL of hydrochloric acid. The flask is completed to 50 mL with hydrochloric acid. Under the same conditions, a blank test is performed. The calibration is obtained by measuring the absorbance of synthetic solutions with progressive concentrations of analyte. The mineral content of the unknown sample solution is then directly deduced by relating its

absorbance value to a calibration line previously established from solutions of elements certified at 1000 ppm.

2.6.8. Total Phenol

Dried pulp (1 g) was macerated in 4 mL of a methanol/water mixture (80:20, v/v) and incubated in an ultrasonic bath at medium intensity for 30 min. The solution was centrifuged at 1200 g for 30 min, and the supernatant was transferred into vials. This procedure was repeated three times. The supernatants were pooled, made up to 50 mL with water, and filtered through a 0.45 µm nylon filter [18].

Total polyphenol content (soluble and hydrolyzable) was determined colorimetrically using the Folin-Ciocalteu method [23], with slight modifications. A 30 µL volume of blank, standard, or filtered extract was placed in a test tube, to which 1.5 mL of distilled water and 2.5 mL of Folin-Ciocalteu reagent (diluted 1:10) were added. The mixture was allowed to stand for 6 min, protected from light, at room temperature. Then, 2 mL of sodium carbonate solution (75 g/L) was added. The mixture was shaken and incubated for 15 minutes in a water bath at 50°C, before being cooled to room temperature. Finally, absorbance was measured at 760 nm using distilled water as a blank. Analyses were performed in triplicate, and a calibration curve was established using gallic acid. Total phenolic content was expressed as mg of gallic acid equivalent (GAE) per 100 g of dry weight.

2.6.9. Total Flavonoid

Dried pulp (1 g) was macerated with 4 mL methanol: water (80:20, v/v) and incubated in ultrasonic bath at medium intensity for 30 min. The solution was centrifuged at 1200 g for 30 min and the supernatant was transferred into vials. The procedure was performed 3 times and the supernatants were combined and made up to 50 mL with water and filtered through a 0.45-micrometer nylon filter [18]. Total soluble flavonoid content was determined using the aluminum chloride colorimetric method [24]. A 2.5 mL volume of blank, standard, or filtered extract was mixed with 1250 µL of distilled water and 750 µL of a 5% sodium nitrite solution; the mixture was allowed to stand for 6 minutes in the dark at room temperature. Subsequently, 750 µL of a 10% aluminum chloride solution was added, and the mixture stood for an additional 5 minutes before the addition of 5 mL of 1 M sodium hydroxide solution and the adjustment of the final volume to 25 mL. Absorbance was measured at 510 nm using a UV-visible spectrophotometer. Total flavonoid contents were calculated from a quercetin calibration curve, and results were expressed as mg QE·100 g⁻¹ fresh weight (FW).

2.7. Statistical Analysis

A one-way analysis was used to determine whether chemical characteristic levels differed according to the fertilizers used. The same test was applied to fruit nutritional quality parameters following the application of organic matter to the soil. Differences between means were evaluated using the Newman-Keuls multiple comparison test and were considered significant at $p < 0.05$. All statistical analyses were performed using Statistica 7.0 software.

3. Results

3.1. Chemical Composition of Organics Fertilizers

The chemical composition of cocoa pods, Moringa leaves and their mixing organic fertilizers are shown in **Table 1**. Theobroma cacao pods (F1) were a good source of potassium (4.33%) and had the highest C: N ratio (37.70). Moringa oleifera leaves fertilize (F5) had a high content of carbon, rich in nitrogen, calcium and potassium with intermediate levels of phosphorus and also contained magnesium. Increasing the rate of Moringa leaves fertilizer improved the nutrient content and resulted in a decrease on the C/N ratio of the formulations. Among all the formulated fertilizers, F4, followed by F3, was found with the adequate quantity of mineral (N, P, K, Ca and Mg) with littlest C/N ratio (**Table 1**).

Table 1. Chemical characteristics of organic fertilizer powders as percentage of dry matter.

Fertilizer	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	C/N
T1	49.00 ± 1.00 ^a	1.32 ± 0.02 ^a	0.26 ± 0.01 ^b	4.33 ± 1.53 ^{ab}	1.00 ± 0.50 ^a	0.33 ± 0.02 ^a	37.21 ± 0.58 ^e
T2	50.00 ± 1.00 ^a	1.50 ± 0.13 ^a	0.27 ± 0.01 ^b	6.00 ± 1.00 ^c	2.33 ± 0.67 ^b	0.38 ± 0.02 ^b	33.55 ± 3.74 ^d
T3	50.70 ± 1.00 ^a	1.87 ± 0.13 ^b	0.23 ± 0.01 ^a	5.00 ± 0.50 ^{bc}	3.00 ± 0.50 ^b	0.46 ± 0.01 ^c	27.09 ± 1.01 ^c
T4	51.00 ± 1.00 ^a	2.38 ± 0.02 ^c	0.28 ± 0.02 ^b	5.50 ± 0.50 ^{bc}	4.00 ± 0.50 ^c	0.50 ± 0.01 ^d	21.43 ± 0.59 ^b
T5	50.00 ± 1.00 ^a	3.00 ± 0.35 ^d	0.35 ± 0.02 ^c	3.00 ± 0.50 ^a	5.00 ± 0.50 ^d	0.57 ± 0.01 ^e	16.79 ± 1.56 ^a
p-value	> 0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with the same letter along the columns were not significantly different at the $p < 0.05$.

3.2. Effects of Organic Fertilizers on Dry Matter and Protein Content of Eggplant Fruit

Mean values for eggplant dry matter content are summarized in **Table 2**. There is a significant difference in dry matter content among eggplants from the various treatments.

3.2.1. Effects of Fertilizers on Dry Matter Content

The analysis results are presented in **Table 2** and **Table 3**. Overall, fertilizer applications had a positive effect on both fruit size and dry matter content compared to the control (T0). At the 1 kg/m² rate, no significant difference ($p > 0.05$) in fruit dry matter content was observed between treatments F1 (8.40%) and F2 (8.35%), which showed the lowest values. In contrast, higher dry matter contents were recorded for treatments F3 (9%), F4 (9.20%), and F5 (8.70%) (**Figure 4**). Furthermore, a gradual decline in dry matter content was observed across successive production cycles for all treatments. At the 2 kg/m² rate, treatments F3 (9.45%) and F4 (9.5%) yielded the highest dry matter contents, surpassing F1 (8.73%), F2 (8.75%), and T0 (8.2%) (**Figure 4**). Significant differences were observed between cycles ($p < 0.001$), revealing that fruit dry matter content was strongly affected by a depletion effect during the last two cycles (C2 and C3) due to the lack of further

fertilizer application. Finally, at the 4 kg/m² rate, treatments F3 (9.75%), F4 (9.9%), and F5 (9.45%) improved dry matter content more effectively than F1 (8.78%) and F2 (8.80%), although no significant difference was detected between F2, F3, and F4 (**Figure 4**).

Table 2. Protein, total polyphenol, and flavonoid contents (expressed on a dry weight basis) were analyzed in the various fruits of the plants harvested at the end of the experiment.

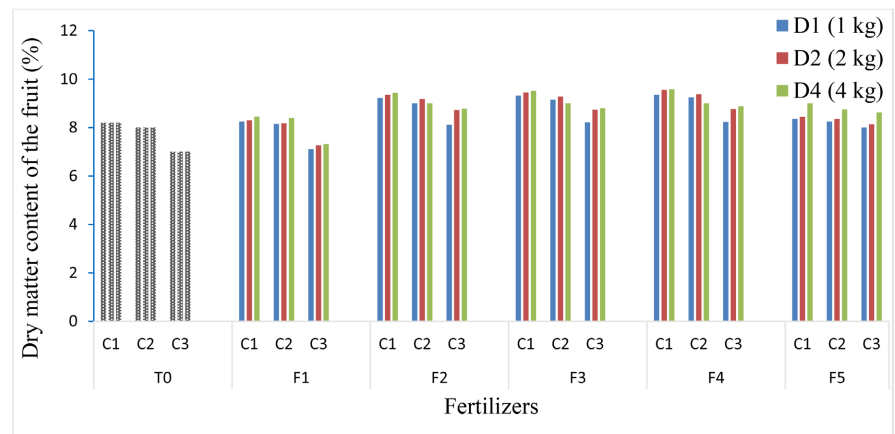
Treatment	Cycle	dry matter (%)			Protein (%)			Polyphenols (%)			Flavonoid (%)		
		1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²
T0	C1	8.20	8.20	8.20	0.64	0.64	0.64	22.40	22.40	22.40	6.00	6.00	6.00
	C2	8.00	8.00	8.00	0.60	0.61	0.60	18.00	18.00	18.00	5.40	5.40	5.40
	C3	7.01	7.01	7.01	0.55	0.54	0.53	16.00	16.00	16.00	5.00	5.00	5.00
F1	C1	8.40	8.73	8.78	0.82	0.83	0.86	66.60	71.40	86.00	19.00	23.00	25.00
	C2	8.15	8.18	8.40	0.78	0.80	0.83	60.12	65.22	76.12	18.00	19.00	20.00
	C3	7.11	7.27	7.32	0.57	0.58	0.63	50.22	51.22	53.22	17.50	17.55	17.70
F2	C1	8.35	8.75	8.80	1.08	1.11	1.19	83.40	96.00	98.00	21.00	23.00	24.00
	C2	8.20	8.35	8.45	1.00	1.06	1.10	78.32	80.32	83.32	17.00	18.30	20.10
	C3	8.12	8.72	8.78	0.67	0.77	0.78	66.12	67.12	68.12	16.23	16.33	17.23
F3	C1	9.00	9.45	9.75	1.13	1.14	1.14	91.40	97.40	98.60	21.00	25.00	25.00
	C2	8.15	9.20	9.25	1.05	1.11	1.11	85.70	87.70	85.70	17.33	18.35	17.45
	C3	8.21	8.74	8.80	1.01	1.09	1.10	74.54	75.56	76.53	16.60	16.80	16.89
F4	C1	9.20	9.50	9.90	1.45	1.47	1.47	98.00	101.40	101.60	26.00	26.00	27.00
	C2	9.15	9.30	9.43	1.17	1.24	1.26	90.00	94.00	95.00	23.00	22.50	23.76
	C3	8.23	8.77	8.88	1.06	1.08	1.10	81.30	83.30	86.30	17.16	17.28	17.67
F5	C1	8.70	8.85	9.45	1.21	1.34	1.38	94.00	97.40	98.00	25.00	27.00	27.00
	C2	8.25	8.35	8.75	1.03	1.04	1.06	86.20	87.20	88.12	20.00	20.54	20.00
	C3	8.00	8.14	8.63	0.57	0.58	0.58	76.12	77.10	77.20	16.00	16.66	16.78

Table 3. Average content of five major minerals in the fruit of *Solanum aethiopicum* (N'Drowa variety) (mg per 100 g dry weight) according to organic fertilizer rates.

Treatments	Cycle	K			Mg			Ca			Fe			Zn		
		1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²	1 kg/m ²	2 kg/m ²	4 kg/m ²
T0	C1	250	250	250	130	129	132	278	280	280	1.14	1.14	1.14	5.78	5.78	5.78
	C2	234	233	234	121	115	114	143	142	144	1.02	1.03	1.01	4.56	4.66	4.77
	C3	220	219	218	98	100	97	115	116	117	0.87	0.88	0.89	2.32	2.22	2.22

Continued

F1	C1	340	340	360	130	130	140	290	310	330	1.27	1.3	1.34	7.33	7.35	7.33
	C2	212	215	220	119	119	120	166	167	178	1.02	1.04	1.04	5.56	6.56	6.54
	C3	144	154	155	103	105	105	103	105	111	0.87	0.88	0.89	2.12	2.35	2.38
F2	C1	350	350	370	140	160	150	299	330	340	1.51	1.66	1.78	7.34	7.35	7.33
	C2	223	225	230	122	127	132	143	232	224	1.11	1.14	1.17	5.23	6.21	6.22
	C3	155	156	160	107	110	115	118	123	125	1.00	0.96	0.99	2.14	2.21	2.34
F3	C1	450	460	470	170	190	200	360	410	430	1.62	1.78	1.8	7.76	7.8	7.81
	C2	309	329	330	133	135	142	213	244	237	1.23	1.33	1.41	4.64	4.65	4.67
	C3	177	187	178	102	104	105	110	117	125	1.01	1.11	1.21	1.45	1.51	1.65
F4	C1	490	510	560	190	220	240	390	420	440	1.65	1.82	1.98	7.97	8.09	8.22
	C2	367	370	367	108	113	124	175	188	185	1.33	1.35	1.43	4.65	5.50	5.65
	C3	165	175	177	99	101	102	104	112	114	1.02	1.05	1.12	1.21	1.25	1.33
F5	C1	390	430	410	150	170	180	380	400	410	1.49	1.55	1.56	7.49	7.52	7.56
	C2	216	217	274	113	121	131	133	136	134	1.21	1.23	1.31	5.34	5.40	5.65
	C3	149	144	156	90	100	103	104	112	116	1.08	1.1	1.16	1.03	1.13	1.31



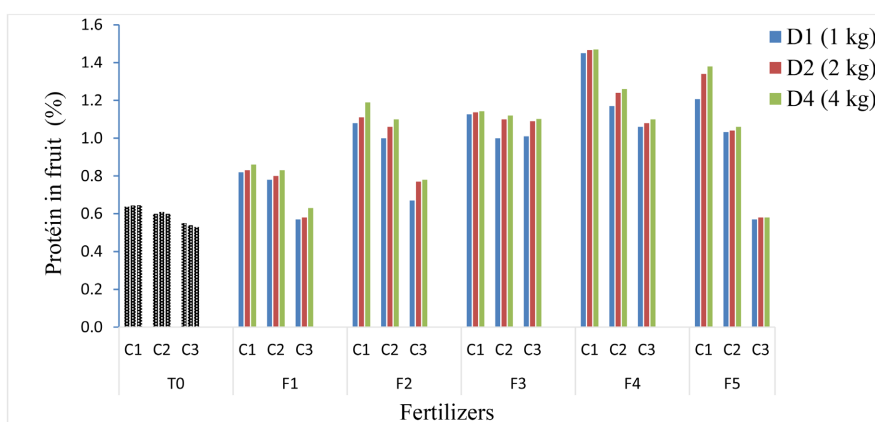
Rate D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cropping cycle; C2: Second cropping cycle; C3: Third cropping cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa pod husks and 25% moringa leaves; F3: Formulation consisting of 50% cocoa pod husks and 50% moringa leaves; F4: Formulation consisting of 25% cocoa pod husks and 75% moringa leaves; F5: Formulation consisting exclusively of moringa leaves; T0: Control without fertilizer.

Figure 4. Eggplant dry matter content according to fertilizer rate and cropping cycle.

3.2.2. Effects of Fertilizers on Protein Content of Eggplant Fruit

Figure 5 shows the protein content of the fruits. Despite increasing fertilizer rates,

protein levels did not vary significantly between fruits from the F2 treatment (1.18% at a rate of 2 kg/m²) and the F3 treatment (1.19% at a rate of 4 kg/m²). The lowest protein content was recorded for the T0 treatment (**Figure 5**). Fruits from the F3 (1.38%) and F4 (1.47%) treatments at the 4 kg/m² rate exhibited high protein levels. The application of increasing rates had an additive effect on the retained protein content.



Rate D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cropping cycle; C2: Second cropping cycle; C3: Third cropping cycle; F1: Formulation composed exclusively of cocoa pod husks; F2: Formulation composed of 75% cocoa pod husks and 25% moringa leaves; F3: Formulation composed of 50% cocoa pod husks and 50% moringa leaves; F4: Formulation composed of 25% cocoa pod husks and 75% moringa leaves; F5: Formulation composed exclusively of moringa leaves; T0: Control without fertilizer.

Figure 5. Protein content of eggplant fruits according to fertilizer rate and cropping cycles.

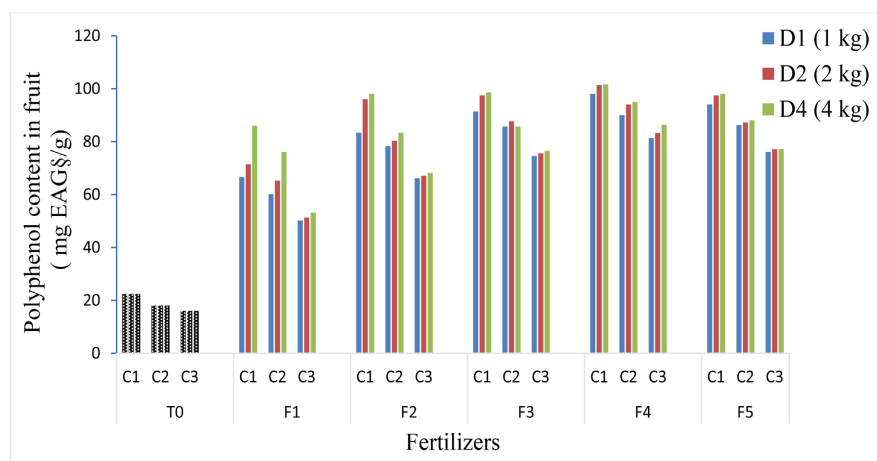
3.3. Effects of Organic Fertilizers on Total Polyphenol and Flavonoids Content of Eggplant Fruits

3.3.1. Effects of Fertilizers on Total Phenol Content

There were no significant differences in total phenol content among the harvested eggplants across treatments F2, F3, F4, and F5 at increasing rates of 1, 2, and 4 kg/m² (**Figure 6**). In contrast, fertilizer F1 showed a significant difference in total phenol content at rates of 1, 2, and 4 kg/m². All values obtained were higher than that of the control T0 (22.4 mg GAE/g). Furthermore, total polyphenol content decreased between the first and third cycles, regardless of the treatment (**Figure 6**).

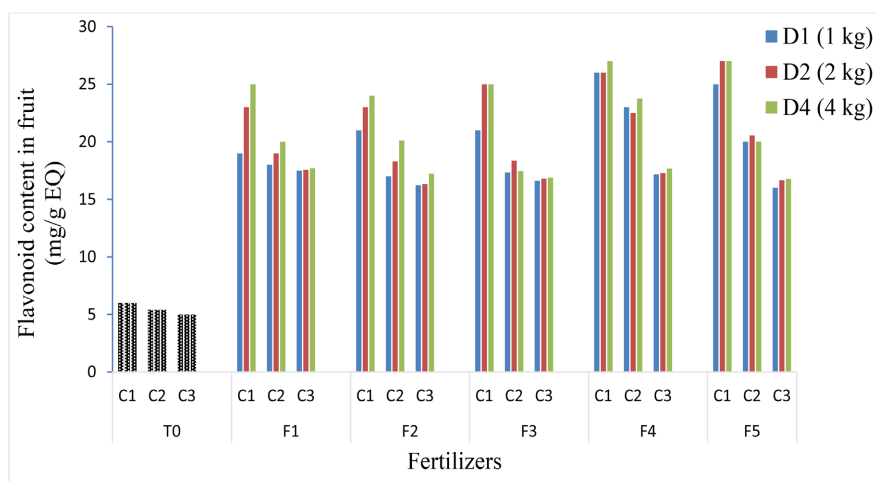
3.3.2. Effects of Fertilizers on Flavonoid Content

Analysis of **Figure 7** reveals observations similar to those for total phenols. For any given treatment, flavonoid content increases with the dosage. This increase was significant across all treatments, particularly for treatments F3, F4, and F5. Relatively high flavonoid levels were observed with treatments F4 and F5, with maximum levels recorded at the 4 kg/m² dosage. Furthermore, flavonoid levels in the fruit from the first cycle were higher than those from the other cycles.



Dose D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cultivation cycle; C2: Second cultivation cycle; C3: Third cultivation cycle; F1: Formulation consisting exclusively of cocoa shells; F2: Formulation consisting of 75% cocoa pod shells and 25% moringa leaves; F3: Formulation consisting of 50% cocoa pod shells and 50% moringa leaves; F4: Formulation consisting of 25% cocoa pod shells and 75% moringa leaves; F5: Formulation consisting exclusively of moringa leaves; T0: Control without fertilizer.

Figure 6. Total polyphenol content of fruits according to fertilizer dose and cycle.



Dose D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cultivation cycle; C2: Second cultivation cycle; C3: Third cultivation cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa pod husks and 25% Moringa leaves; F3: Formulation consisting of 50% cocoa pod husks and 50% Moringa leaves; F4: Formulation consisting of 25% cocoa pod husks and 75% Moringa leaves; F5: Formulation consisting exclusively of Moringa leaves; T0: Control without fertilizer.

Figure 7. Flavonoid content of fruits according to fertilizer dose and cultivation cycle.

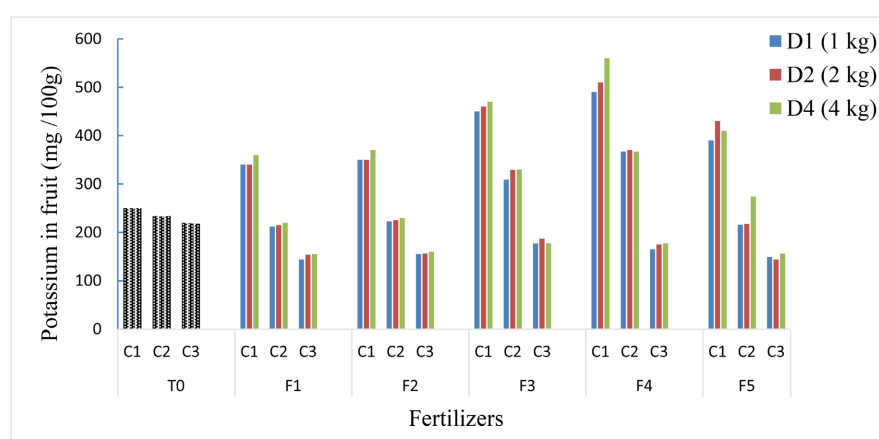
3.4. Effects of Organic Fertilizers on the Macro- and Micronutrient Content of Eggplant Fruits

The minerals analyzed are in **Table 3**.

3.4.1. Effects of Fertilizers on the Potassium Content of Eggplants

Figure 8 shows the potassium content of the fruit according to treatments, application rates, and cycles. Potassium levels in the fruit increased significantly with increasing application rates (1, 2, and 4 kg/m²). At the 1 kg/m² rate, the highest levels were observed with treatments F3 (450 mg/100g) and F4 (490 mg/100g), followed by F5 (390 mg/100g), F2 (350 mg/100g), and F1 (340 mg/100g). The control (T0) showed the lowest level (250 mg/100g). Potassium levels decreased during the two cycles in which no fertilizer was applied (**Figure 8**).

At the 2 kg/m² rate, treatments F3 (460 mg/100g) and F4 (510 mg/100g) yielded the highest levels compared to the other treatments (**Figure 8**). Furthermore, regardless of the application rate, the highest potassium levels were obtained with treatments F3 and F4.



Dose D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cropping cycle; C2: Second cropping cycle; C3: Third cropping cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa pod husks and 25% moringa leaves; F3: Formulation consisting of 50% cocoa pod husks and 50% moringa leaves; F4: Formulation consisting of 25% cocoa pod husks and 75% moringa leaves; F5: Formulation consisting exclusively of moringa leaves; T0: Control (no fertilizer).

Figure 8. Potassium content in fruit according to fertilizer dosage and cropping cycles.

3.4.2. Effects of Fertilizers on the Magnesium Content of Eggplants

Fruit magnesium content increased in proportion to the application rates, regardless of the treatment (**Figure 9**). Magnesium levels in the eggplants were particularly high with treatments F3 and F4, irrespective of the dosage. A significant difference in magnesium content was observed between cropping cycles. Analysis revealed that treatments at the 4 kg/m² rate were highly significant ($p < 0.001$) compared to the 2 kg/m² and 1 kg/m² rates, as well as the control (T0). Specifically, treatments F3 (200 mg/100g) and F4 (240 mg/100g) yielded the highest values among all treatments (**Figure 9**). Treatments T0 and F1 fell within the same range of content levels.

3.4.3. Effects of Fertilizers on the Calcium Content of Eggplants

Fertilizer application at a rate of 1 kg/m² resulted in improved calcium levels com-

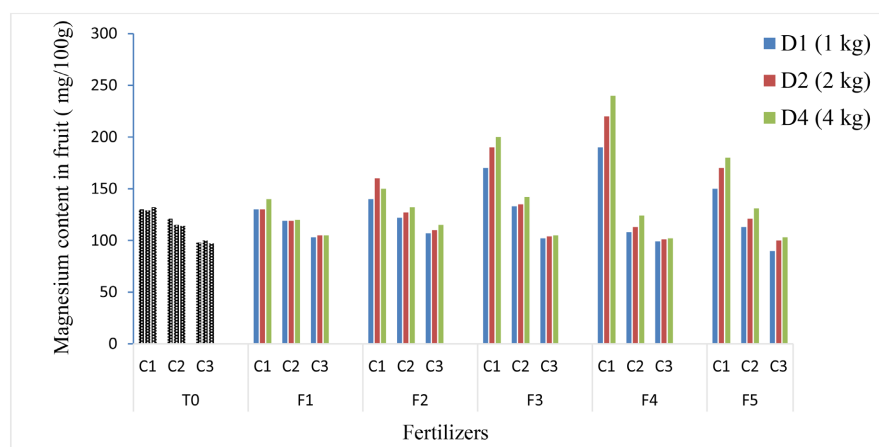
pared to the T0 control. Specifically, calcium levels in eggplants from treatments F1 and F2 fell within the same range (at the 5% significance level). These eggplants showed lower values compared to those from treatments F3 (360 mg/100g), F4 (390 mg/100g), and F5 (380 mg/100g) (**Figure 10**). Regarding the cropping cycles, a progressive decline in calcium levels was observed across all treatments.

Furthermore, at the 2 kg/m² application rate, treatments F3 (410 mg/100g) and F4 (420 mg/100g) yielded the highest calcium levels compared to treatments F1 (310 mg/100g), F2 (330 mg/100g), and T0 (280 mg/100g). Significant differences were observed across the cycles. Additionally, the results revealed that calcium levels were significantly influenced by the absence of fertilizer application during the final two cycles (C2 and C3). Overall, the treatments had a positive effect on eggplant calcium levels. At the 4 kg/m² rate, eggplants from treatments F3 (430 mg/100g), F4 (440 mg/100g), and F5 (410 mg/100g) exhibited higher levels than those from F1 (330 mg/100g) and F2 (340 mg/100g) (**Figure 10**). Analytical results indicated a decline in levels over the course of the cycles.

3.4.4. Effects of Fertilizers on Iron Content in Eggplants

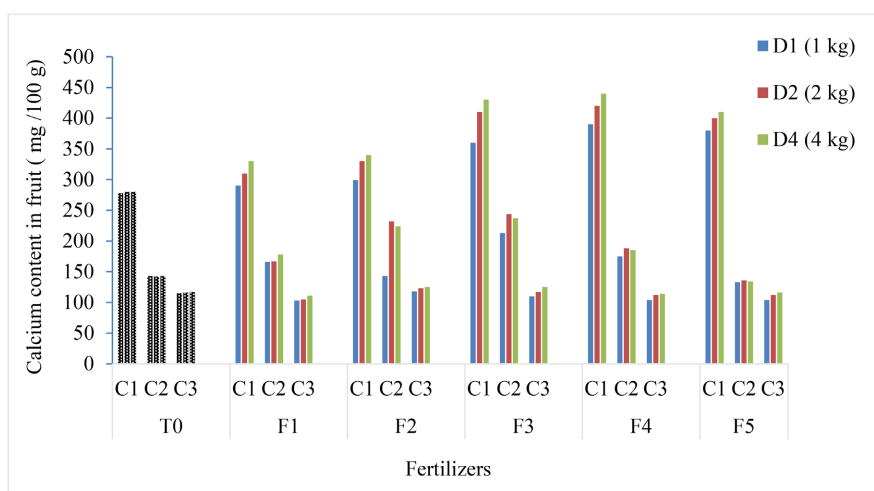
Iron content in eggplants ranged from 1.14 to 1.65 ppm at the 1 kg/m² application rate. The effect of the treatments on eggplant iron content was significant ($p = 0.001$). Fertilizers F3 and F4 resulted in the highest iron levels, at 1.62 and 1.65 ppm, respectively (**Figure 11**). The lowest iron levels were observed with F1 (1.27 ppm), F5 (1.49 ppm), and F2 (1.51 ppm).

At the 2 kg/m² application rate, there was a significant difference in content levels among the treatments at the 5% significance level. Treatments F3 (1.78 ppm) and F4 (1.82 ppm) recorded the highest iron levels.



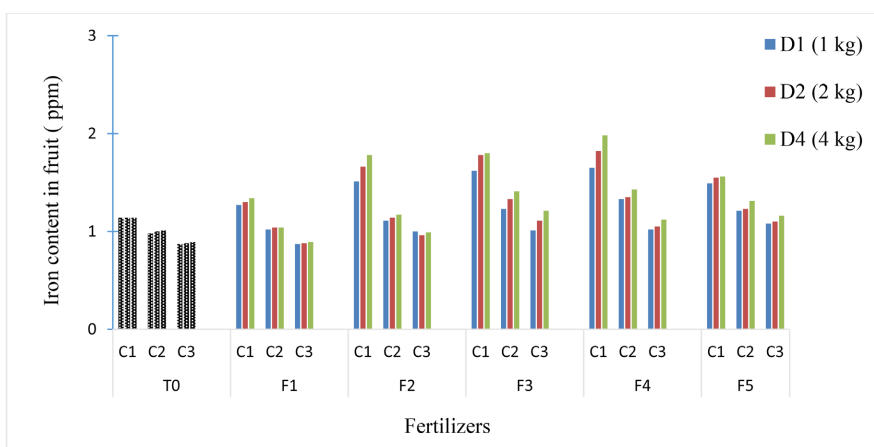
Dosage D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cultivation cycle; C2: Second cultivation cycle; C3: Third cultivation cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa husks and 25% Moringa leaves; F3: Formulation consisting of 50% cocoa husks and 50% Moringa leaves; F4: Formulation consisting of 25% cocoa husks and 75% Moringa leaves; F5: Formulation consisting exclusively of Moringa leaves; T0: Control without fertilizer.

Figure 9. Magnesium content of fruits according to fertilizer dosage and cycle.



Dosage D1: 1 kg·m⁻² of fertilizer applied to the growing medium; D2: 2 kg·m⁻² of fertilizer applied to the growing medium; D3: 4 kg·m⁻² of fertilizer applied to the growing medium. C1: First cultivation cycle; C2: Second cultivation cycle; C3: Third cultivation cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa pod husks and 25% Moringa leaves; F3: Formulation consisting of 50% cocoa pod husks and 50% Moringa leaves; F4: Formulation consisting of 25% cocoa pod husks and 75% Moringa leaves; F5: Formulation consisting exclusively of Moringa leaves; T0: Control without fertilizer.

Figure 10. Fruit calcium content according to fertilizer dosage and cultivation cycles.



Dosage D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cultivation cycle; C2: Second cultivation cycle; C3: Third cultivation cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa pod husks and 25% moringa leaves; F3: Formulation consisting of 50% cocoa pod husks and 50% moringa leaves; F4: Formulation consisting of 25% cocoa pod husks and 75% moringa leaves; F5: Formulation consisting exclusively of moringa leaves; T0: Control without fertilizer.

Figure 11. Iron content of fruits according to fertilizer dosage and cultivation cycles.

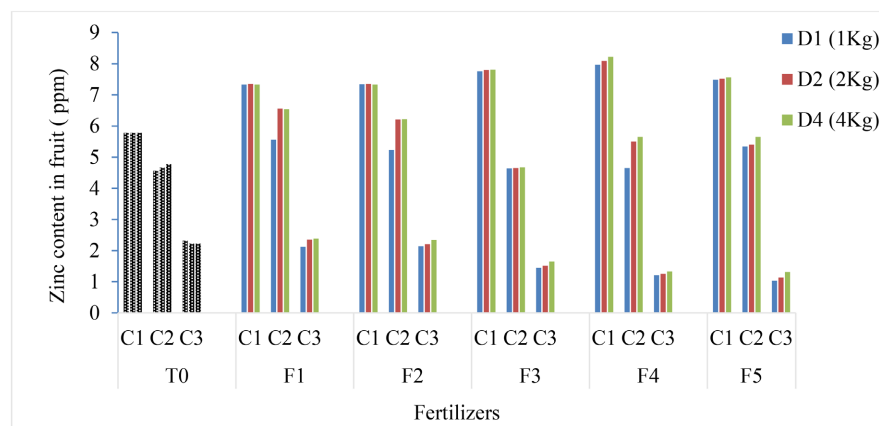
Furthermore, organic fertilizers increased iron levels in eggplants at the 4 kg/m² application rate. The highest iron levels in the eggplants were recorded with treatments F3 (1.89 ppm) and F4 (1.98 ppm). Regarding the cropping cycles, iron levels

in the eggplants decreased progressively (**Figure 11**).

3.4.5. Effects of Fertilizers on Zinc Content in Eggplants

Zinc levels in eggplants increased significantly with increasing application rates (1, 2, and 4 kg/m²) (**Figure 12**). At the 1 kg/m² rate, the highest levels were observed with treatments F3 (7.76 ppm) and F4 (7.97 ppm), followed by F5 (7.49 ppm), F2 (7.34 ppm), and F1 (7.33 ppm). The control (T0) showed the lowest level (5.78 ppm). Furthermore, zinc levels decreased during the two cycles in which no fertilizer was applied (**Figure 12**).

At the 2 kg/m² rate, treatments F3 (460 mg/100g) and F4 (510 mg/100g) also yielded the highest levels compared to the other treatments. Moreover, regardless of the application rate, the highest zinc levels were obtained with treatments F3 and F4. Within each cycle, there was no significant difference in zinc levels in the eggplants (**Figure 12**).



Dose D1: 1 kg·m⁻² of fertilizer applied to the soil; D2: 2 kg·m⁻² of fertilizer applied to the soil; and D3: 4 kg·m⁻² of fertilizer applied to the soil. C1: First cultivation cycle; C2: Second cultivation cycle; C3: Third cultivation cycle; F1: Formulation consisting exclusively of cocoa husks; F2: Formulation consisting of 75% cocoa pod husks and 25% Moringa leaves; F3: Formulation consisting of 50% cocoa pod husks and 50% Moringa leaves; F4: Formulation consisting of 25% cocoa pod husks and 75% Moringa leaves; F5: Formulation consisting exclusively of Moringa leaves; T0: Control without fertilizer.

Figure 12. Zinc content of fruits according to fertilizer dosage and cultivation cycles.

4. Discussion

This study investigated the effects of the incorporation of moringa leaves in the formulation of fertilizer enriched with cocoa shells pods on the quality of the nutritive and bioactive components of eggplant. The addition of more amount of moringa leaves in cocoa pods improved the concentration of N, P, K, Ca and Mg of organic fertilizers and their carbon-to-nitrogen ratio C/N progressively declined. The extent of mineral was comparable to values reported for Cocoa pods from Ghana [22] [23] and Moringa leaves as reported by [24]. Frequently, a narrow C/N ratio of organic matter means easy decomposition process and adequate releasing of nutrients available for crops [25]. Therefore, fertilizers 4 and F5 met

the quality standards of Canadian Compost Guidelines: C/N ratio ≤ 25 , pH 5.5 - 8.5, a minimum concentration of total N, P, K, Ca and Mg at 0.60, 0.25, 0.20, 3.0 and 0.30%, respectively [26]. Fertilizer F4 had significantly higher concentration of potassium than F5. Potassium is a very mobile element in the soil; so, the K levels provided by fertilizer F5 are not sufficient to compensate the losses by leaching. Some studies supported the idea that potassium play a key role in the translocation of the new synthesized photosynthates, their mobilization and storage on fruit [27]. The percent of added Moringa leaves on fertilizer and its relationship with the dose of applied affected the dry matter and protein content of eggplant fruit. From the aforementioned, the incorporated moringa leaves encourages the activity of soil organisms, accelerated the decomposition, released a huge amount of all kind's minerals (N, P K, Ca, Mg) in the correct mixture for the crops thus improved biochemical mechanism needed for nutrient accumulation in fruit [28] [29].

The eggplant fruits mostly possess low dry matter as documented for different varieties. The mean of dry mater (8.20 and 9.58 per 100g of fresh weight) was slightly higher than proximate composition content of 8.8 per 100g of fresh weight reported for of *Solanum aethiopicum* L [30]. High moisture content implies a relative lower water content which is a desirable characteristic for better postharvest conservation. Protein is one of the most important nutrients for human diet. The variability in protein content in the eggplant could be primarily Variations in protein content in response to fertilization with cocoa pod husks and *Moringa* leaves were statistically significant, ranging from 0.64 to 1.65 g per 100 g of fresh weight. Other authors have also reported values between 1.31 and 1.85 g for *S. aethiopicum* L. fruits grown in different regions of Nigeria [31] [32], attributed to the variety. Phenolic compounds have been identified as the primary bioactive compounds responsible for the antioxidant effects of eggplant. Total phenolic and flavonoid contents decrease in the absence of organic fertilization. These results align with those of [33], who observed that lettuces treated with organic fertilizers exhibited higher polyphenol and flavonoid levels than control plants. Furthermore, when using fertilizer based on cocoa pod husks and moringa leaves, eggplant fruits harvested from plants receiving the highest nitrogen and potassium inputs tended to show the highest phenolic compound levels. The same trend was observed for flavonoid content in eggplants, which tends to increase with higher nitrogen fertilization rates. The results obtained here contrast with those of [34], who showed that tomatoes harvested from plants receiving the lowest nitrogen input tended to exhibit the highest phenolic compound content. Phenolic compound concentrations were correlated with the carbon-to-nitrogen ratio as well as with interactions involving minerals present in the fertilizer. The enzyme phenylalanine ammonia-lyase, involved in the biosynthesis of phenolic compounds, was regulated by nitrogen [35]. [28] showed that, at moderate potassium fertilization levels, increasing nitrogen input led to a significant decrease in total polyphenol content; conversely, when potassium inputs were high, treatments with higher nitrogen levels resulted in higher concentrations of these compounds. The phenolic

compound contents of eggplants grown with the application of cocoa pods and moringa leaves ranged from 22.40 to 101.6 mg GAE g⁻¹ of fresh weight. These results are higher than the values reported by several authors [19] [35] but lower than those observed by Nwanna *et al.* [36] and Kaur *et al.* [37] [38]. The significant differences in phenolic compound content observed among the accessions suggest a dependence on genotype and climatic conditions [39].

Minerals play a role in functions such as maintaining heart rhythm, muscle contractility, bone and tooth formation, acid-base balance, the regulation of cellular metabolism, and enzymatic reactions [40]. It is possible that applying fertilizer based on cocoa pod husks enriched with *Moringa* to the soil stimulated the accumulation of essential minerals in the fruit. Potassium was the major element in the eggplant, with concentrations ranging from 250 to 560 mg per 100 g of fresh weight. Calcium was the second most abundant macronutrient in the N'Drowa eggplant. Magnesium levels were 2 to 2.3 times lower than potassium levels. The ranges of values observed for macro- and micro-element composition vary considerably but align with previous data on commercial eggplants, with the exception of calcium [41]. According to Mauro *et al.* [42], phosphorus supply and genotype influence the mineral composition of the fruit pulp of the *Solanum torvum* eggplant. In this regard, it has been reported that an adequate N/P ratio in the soil optimizes root architecture as well as the plant's capacity to absorb these two macronutrients [43].

Plants cannot synthesize minerals; these are supplied by the soil. Since the human body is also unable to synthesize minerals, they must be obtained through the diet. Using the F4 formulation at a rate of 4 kg/m² could therefore mitigate the decline in mineral content in fruits and vegetables observed by various authors [36] [44]. An abundance of nutrients such as potassium (K) and nitrogen (N) promoted proper plant development and fruiting. Consequently, treatments F3 and F4 resulted in higher nutritional levels. This nutrient richness stems from the combined effect of the organic fertilizer and climatic/environmental conditions, with the latter significantly influencing nutrient content. Furthermore, trace element levels in the eggplants varied slightly between treatments due to the application of increasing doses. This was not the case for total zinc and polyphenol levels, which maintained the same trends despite increasing the fertilizer dose from 2 kg/m² to 4 kg/m² (D4). In other words, there appears to be a limit to the use of fertilizers and, more generally, to all growth factors. Indeed, regardless of the fertilizer used, fertilizer efficiency decreases as application rates increase [45]. These results demonstrate the relevance and necessity of using optimal doses, as high doses do not guarantee good yields. This study confirms the observations of [46], who reached similar conclusions when studying the impact of increasing compost doses on Chinese cabbage yields in the Democratic Republic of the Congo. In this study, the 4 kg/m² dosage yielded the highest output compared to the 1 kg/m² and 2 kg/m² dosages. The minerals measured in the harvested fruit play a crucial role in combating various conditions; for instance, zinc and iron

help fight inflammatory diseases [47]. Notably, the zinc content (8.22 ppm)—close to the reference value (10 ppm)—could play a major role in immunity and growth. Despite the increase in dosage, zinc levels remained stable.

The recorded macronutrient contents of K (250 to 560 mg/100g), Ca (280 to 440 mg/100g), and Mg (130 to 240 mg/100g) are low compared to their respective reference values of 2000, 800, and 375 mg/100g [48]. Potassium helps regulate blood pressure [49]. [50] and [51] showed that a daily potassium supplementation of 4700 mg would decrease blood pressure by 4.4 to 2.5 mm Hg. Calcium, for its part, exhibits anticarcinogenic activity as it reduces the risk of colorectal cancer [52]. Magnesium acts as an enzymatic cofactor that limits the conversion of linoleic acid into γ -linolenic acid. The latter can contribute to the synthesis of prostaglandins, substances that cause brain disorders [53]. If the minerals are bioavailable, consuming this eggplant variety could prevent hypertension, cancer, and oxidative stress by scavenging free radicals. Indeed, the antioxidants contained in this eggplant variety could enable the body to reduce oxidant levels, which are hazardous to health.

The values of the micronutrients iron and zinc determined in the eggplants in this study increased according to the dose and treatment. The highest contents were obtained at the 4 kg/m² dose with the F4 treatment. The contents reached 1.65 ppm for Fe and 8.22 ppm for zinc, representing respective increases of 37.83% and 29.68% compared to T0. These values are consistent with results obtained in several studies on various eggplant varieties [54] [55]. Furthermore, zinc and iron are essential for human health. More than 30% of the world's population is anemic, which could be attributed to iron deficiency. Iron is an essential component of bodily systems involved in oxygen utilization. Iron deficiency during childhood and adolescence impairs physical and mental development [56]. Thus, the iron content (1.14 to 1.65 ppm) recorded in this African N'DROWA eggplant variety could be valuable for enriching the human diet. Regarding zinc, it is a micronutrient required for protein and carbohydrate metabolism, the immune system, wound healing, growth, and vision. Zinc deficiency can induce growth retardation, a weakened immune system, and a loss of taste and skin sensitivity. Similar results have been validated in the United States. Indeed, low zinc levels have been associated with growth retardation, poor appetite, and an underdeveloped sense of taste [57].

5. Conclusion

The partial substitution of cocoa pods with moringa leaves had positive effects on eggplant *Solanum aethiopicum* L N'Drowa fruits quality. The increasing rate of moringa leaves improved the characteristics of fertilizers in terms of N, P, Ca, Mg concentration and C/N ratio and thereby enhanced nutritive and bioactive components content. A significant variation in dry matter, protein, total phenol, flavonoid, macro and micro minerals content were observed among fruit produced under moringa-substituted cocoa pod versus cocoa pods fertilization. The ferti-

lizer F4 (25% cocoa pods + 75% cocoa pods) had a desirable quality standard of Canadian Compost Guidelines and should be reasonably used as organic alternative to make eggplant fruits bio fortified.

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Author Contributions

AKY performed the experiments and wrote the initial draft of the manuscript. CDA and AKY conceived and designed the experiments and proofreading of the manuscript. ANE validated data processing. A.S.J. assisted with literature search, analyzed and interpreted the data and revised the final draft of the manuscript. All authors have read and agreed to the published version of the manuscript. Conceptualization, AKY and CDA; methodology, ANE; software, ANE; validation, ASJ, CDA, and AKY; formal analysis, AKY; investigation, AKY; resources, ANE; data curation, AKY; writing—original draft, AKY; writing—review and editing, CDA; visualization, CDA; supervision, ASJ; project administration, AKY; funding acquisition, AKY. All authors have read and approved the published version of the manuscript.

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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