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Comparative effects of organic, mineral and organo-mineral fertilizers on the yield and nutritional quality of orange-fleshed sweet potatoes in urban and rural areas of Côte d'Ivoire

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Abstract

The low fertility of soils in Côte d'Ivoire is a major constraint on the productivity and nutritional quality of orange-fleshed sweet potatoes (OFSP). This study evaluated the comparative effect of organic fertilization (OF), mineral NPK fertilization (MF), and organo-mineral fertilization (OMF) on tuber yield and nutritional quality in two agroecological zones, Abidjan (urban) and Tiangakaha (rural), using a completely randomized block design. The results indicate a significant improvement in yield and nutritional density under all fertilizer treatments compared to the control ($p < 0.05$), with FOM consistently performing better. The maximum yield (8.36 t/ha) was recorded in Tiangakaha under FOM. This fertilization also led to a significant increase in protein (2.04 %), dietary fiber (6.25 %), and β-carotene (10.4 mg/100 g DM in Abidjan; 9.7 mg/100 g DM in Tiangakaha), compared to the control (7.1 mg/100 g DM). Essential minerals were significantly enriched, particularly potassium (up to 512 mg/100 g DM), magnesium (41 mg/100 g DM) and iron (0.88 mg/100 g DM), while mineral fertilization promoted calcium accumulation (52 mg/100 g DM). Conversely, carbohydrates and starch were found in higher concentrations in unfertilized plots. These results demonstrate that the integration of organic and mineral amendments is an effective agronomic biofortification strategy, simultaneously optimizing the yield and nutritional density of OFSPs. The adoption of fertilization practices adapted to local soil conditions is therefore a sustainable lever for strengthening food security and contributing to the reduction of micronutrient deficiencies in Côte d'Ivoire.

Keywords: Orange-Fleshed Sweet Potato; Integrated Fertilization; Yield; Nutritional Density; Agronomic Biofortification

1. Introduction

The sweet potato (*Ipomoea batatas* L.) is a major food crop in tropical and subtropical regions due to its high ecological plasticity and ability to grow in difficult soil and climate conditions [1]. Among the different cultivars, the orange-fleshed sweet potato (OFSP) is particularly notable for its high beta-carotene content, the main precursor of vitamin A, as well as its richness in complex carbohydrates, dietary fiber, phenolic compounds, and essential minerals, which give it major nutritional and health benefits [2,3].

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In Côte d'Ivoire, sweet potatoes are grown every year in all regions, where they play an important role in food security and income generation for rural households [4]. In 2017, national production was estimated at around 54,100 tonnes [5], mainly from white and yellow-fleshed varieties grown in the north and center, particularly around the cities of Bouaké and Korhogo [6]. However, given the persistence of vitamin A deficiency, particularly among children and women of childbearing age, the promotion of orange-fleshed sweet potato varieties is a priority nutritional strategy [7]. The great culinary versatility of this crop, whose tubers can be eaten boiled, roasted, fried or processed into flour, and whose leaves can be used as vegetables, also contributes to strengthening food security and improving people's livelihoods [8].

However, despite this growing interest, the productivity and nutritional quality of OFSP are closely linked to soil fertility. Indeed, more than 40 % of soils in sub-Saharan Africa are now considered nutrient-depleted [9]. In Côte d'Ivoire, progressive land degradation, characterized by low organic matter content, increased acidity and nutrient depletion, is a major constraint on production [10]. In urban areas in the south and rural areas in the north, continued soil exploitation, monoculture and insufficient organic matter inputs contribute to soil depletion, compromising both yield and the concentration of nutrients and bioactive compounds in tubers [11].

Faced with this degradation, sustainable improvement in soil fertility relies on the complementary use of mineral, organic and organo-mineral fertilizers. Mineral fertilizers provide a rapid supply of nutrients, while organic amendments improve soil structure, biological activity and water retention capacity. Organo-mineral fertilizers combine the advantages of both approaches by providing a balanced and sustained supply of nutrients [12]. Numerous studies recommend combining organic and mineral fertilizers in appropriate proportions to sustainably improve the fertility of tropical soils [13, 14].

Nevertheless, the use of fertilizer raises questions about preserving the nutritional quality of tubers. In Côte d'Ivoire, few studies have taken an integrated approach to the impact of fertilization practices on the nutritional value of orange-fleshed sweet potatoes (OFSP), particularly with regard to their carbohydrate profile and bioactive compounds, even though this crop plays a strategic role in national policies to combat malnutrition.

In this context, it seems necessary to compare the effectiveness of organic, mineral and organo-mineral fertilizers in different environments such as the urban area of Abidjan and the rural area of Tiangakaha. The objective of this study is therefore to evaluate the comparative effect of these fertilizers on the yield and nutritional quality of OFSP, with a view to identifying fertilization strategies that are both sustainable and effective, capable of meeting the challenges of food and nutritional security in Côte d'Ivoire.

2. Materials and Methods

2.1. Plant material

The plant material (Figure 1) used in this study consisted of orange-fleshed sweet potato tubers (OFSP) from cuttings grown at two experimental sites: Nangui Abrogoua University in Abidjan, representative of the coastal urban environment, and Tiangakaha in Korhogo, located in a rural area. The selected cuttings showed satisfactory vigour, uniform morphology and high tuberization potential.

Figure 1 Sweet potato tubers with orange flesh

2.2. Fertilizers used

2.2.1. Mineral fertilizer

The mineral fertilizer (Figure 2) used, PARTNER (12% N, 11% P_2O_5, 18% K_2O), served as a source of directly assimilable nutrients, promoting chlorophyll synthesis and the development of the plants' aerial parts. A total dose of 351 kg/ha was applied in two successive applications, the first when the cuttings were planted and the second 40 days later, ensuring adequate nutrient availability throughout the growing cycle.

a: organic fertilizer ; b: organo-mineral fertilizer ; c: mineral fertilizer

Figure 2 Various types of fertilizers used

2.2.2. Organic fertilizers

The organic inputs used were sourced locally, including poultry manure, cattle manure and rice bran. The compost was produced in two pits measuring 9 m^2 and 30 cm deep, the bottoms of which were covered with tarpaulins to reduce losses and retain moisture. The materials were arranged in successive layers with cattle dung at the bottom, chicken manure in the middle and rice bran on top, and watered regularly to promote decomposition. Each pit received approximately 1,000 kg of organic matter. The quantities and proportions of inputs are shown in Table 1.

Table 1 Quantities and proportions of organic inputs used in the preparation of fertilizers

Fertilizer type	Chicken droppings (kg)	%	Beef excrement (kg)	%	Rice husks (kg)	%	Total (kg)
Enriched	865.5	84.22	68.2	6.63	94	9.15	1027.7
Non-enriched	841.7	81.17	91.3	8.80	104	10.03	1037

2.2.3. Organo-mineral fertilizer (OMF)

After two months of composting, one of the piles was amended with mineral fertilizers (urea, triple superphosphate, PARTNER and potassium sulphate) (Table 2) to obtain organo-mineral fertilizer (OMF). The unenriched compost was designated as organic fertilizer (OF).

Table 2 Dosages of mineral fertilizers used for the production of OMF

Fertilizer	N-P-K formula	Quantity (kg)
Urea	46-0-0	11.95
TSP	0-46-0	47.8
PARTNER	12-11-18	15
Potassium sulphate	0-0-51	60

TSP : superphosphate triple ; PARTNER : commercial name for a ternary mineral fertilizer

2.3. Experimental system and planting methods

The trial (Figure 3 and Figure 4) was set up using a Fisher block design comprising four treatments and four replicates, giving a total of 16 plots, each measuring 20 m^2 (5 × 4 m). Each plot consisted of three growing beds measuring 5 × 4 ×

0.2 m. The treatments applied were as follows: Control (C), Mineral fertilizer (MF), Organic fertilizer (OF) and Organo-mineral fertilizer (OMF). The cuttings, 15 to 20 cm long (3 to 4 nodes), were planted in two rows per board, with a spacing of 0.50 m between rows and 0.40 m between plants. They were buried two-thirds of their length to promote good rooting and optimal tuberization.

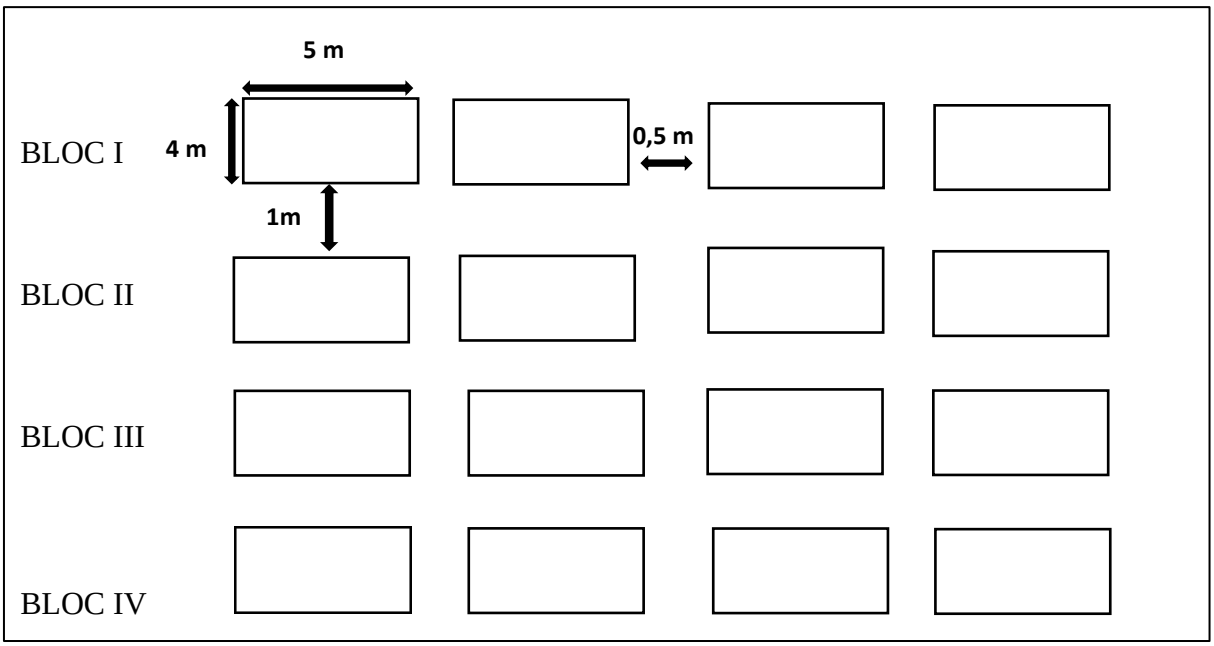


Figure 3 Conceptual diagram of the experimental system for OFSP cultivation

Figure 4 Diagram of the experimental system used for OFSP cultivation

2.4. Harvest

Harvesting took place four months after planting the cuttings, at the optimal stage of tuber maturation. Sampling was carried out using a 1 m^2 quadrat to ensure good representativeness of each plot. The tubers from each treatment were then grouped together to form four final samples per site, then sent to the Biocatalysis and Bioprocesses Laboratory (Nangui ABROGOUA University) for analysis.

2.5. Sample preparation

To obtain the starch, the tubers were first carefully washed, peeled and then cut into thin slices. They were then dried at 105 °C for 24 hours before being ground to produce OFSP starch powder. The samples obtained were stored in airtight jars at room temperature, which allowed their chemical properties to be maintained until analysis.

2.6. Chemical analyses

2.6.1. Chemical composition analysis

The chemical composition of OFSP starch powder was analyzed at the Biocatalysis and Bioprocesses Laboratory of Nangui ABROGOUA University (Abidjan, Côte d'Ivoire). Parameters such as dry matter, ash, lipids and dietary fiber were evaluated according to the official methods of the AOAC [15].

Reducing sugars were measured using the method of Bernfeld [16], while total sugar content was determined according to the protocol described by Dubois et al. [17]. Total carbohydrates were obtained by differential calculation. Protein content was estimated by multiplying the amount of nitrogen by the conversion factor 6.25, in accordance with the micro-Kjeldahl distillation method [15].

2.6.2. Quantification of free sugars

Free sugars, namely glucose, fructose and sucrose, were quantified using an enzymatic method adapted from the protocols of Kunst et al. [18] and Beutler [19], using the Megazyme K-SUFRG kit (Megazyme International Ireland Ltd., Wicklow, Ireland). Four cuvettes were prepared and labelled: 'blank sucrose', "sucrose", 'blank free sugar' and 'free sugar'. The cuvettes dedicated to sucrose each received 0.20 mL of β-fructosidase. Next, 0.10 mL of sample extract was added to the 'sucrose' and 'free sugar' cuvettes. After homogenization, the mixture was incubated at 30°C for 5 minutes. Distilled water was then added in volumes of 1.9 mL, 2.0 mL, 2.1 mL and 2.2 mL to the four cuvettes. To each cuvette, 0.10 mL of buffer solution and 0.10 mL of NADP/ATP solution were added, followed by a further 3-minute incubation. An initial absorbance (A_1) was measured at 340 nm. Then, 0.02 mL of the HK/G6P-DH solution was added, allowing a second reading (A_2). Finally, 0.02 mL of phosphoglucose isomerase (PGI) was added to the 'virgin free sugar' and 'free sugar' cuvettes, before a third absorbance measurement (A_3) at 340 nm. The free sugar content was calculated from the different readings and expressed in g per 100 g of dry matter (g/100 g DM).

2.6.3. Determination of starch, amylose and amylopectin

The total starch, amylose, and amylopectin contents were determined using the iodine colorimetric method described by Jarvis and Walker [20]. The starch samples, which had been previously solubilized in an alkaline medium and then neutralized, were reacted with an I_2/KI solution to form colored complexes. Absorbance was measured by spectrophotometry at 580 nm for total starch and at 720 nm for amylose, based on their specific iodine-binding properties. Quantification was performed using calibration curves established with standards, taking into account dilution factors. The amylopectin content was then obtained by subtracting the amylose content from the total starch content.

2.6.4. Analysis of bioactive compounds

Phenolic compounds were extracted using methanol in accordance with the method described by Singleton et al. [21]. The total polyphenol content was determined using the Folin-Ciocalteu method [21], while flavonoids were quantified according to the protocol of Meda et al. [22]. The β-carotene concentration was assessed using the method described by Aké et al. [23] and vitamin C was measured using the procedure described by Pelletier [24], based on samples prepared from fresh material before drying and grinding.

2.6.5. OFSP mineral analysis

Mineral analysis was performed by point microanalysis using energy dispersive spectrometry coupled with SEM (SEM/EDS). For each OFSP and each treatment, 10 mg of ash residues were collected and then spread evenly on pads covered with double-sided adhesive carbon tape. The pads were mounted on the SEM stage (capable of holding 8 pads) and positioned on the SEM chamber stage for X-ray microanalysis (EDS).

2.7. Statistical analyses

The data were analyzed using SPSS 17.0 software and are presented as means ± standard deviation (n = 3). The effect of the different fertilization treatments was evaluated using one-way analysis of variance (ANOVA). Multiple comparisons between means were performed using Duncan's test with a significance threshold of 5 % ($p < 0.05$). In addition, a principal component analysis (PCA) was conducted to distinguish between the different OFSP preparations based on their biochemical characteristics.

3. Results

3.1. Yield of orange-fleshed sweet potatoes according to fertilizer treatments and growing areas

The yield of orange-fleshed sweet potatoes (OFSP) was significantly affected by the types of fertilization and the locations studied ($P < 0.05$) (Table 3). The results reveal notable variations in the response of plants to treatments depending on the cultivation site, compared to the unfertilized control.

In Abidjan, the lowest yield was observed in the control (OFSP-C), with an average value of 2.57 ± 0.23 t/ha. The application of mineral fertilizer (OFSP-MF) resulted in a significant increase in yield, which reached 5.13 ± 0.12 t/ha. Similarly, organic fertilizer (OFSP-OF) improved production, with a yield of 5.27 ± 1.02 t/ha. However, treatment with organo-mineral fertilizer (OFSP-OMF) stood out with the highest performance, recording an average yield of 6.45 ± 0.09 t/ha.

In Tiangakaha, the control yield is lower than that observed in Abidjan, with a value of 2.22 ± 0.61 t/ha. The addition of mineral fertilizer leads to a significant increase in yield, which rises to 3.87 ± 0.29 t/ha. Organic fertilizer produced a more marked improvement, with a yield of 5.87 ± 0.34 t/ha. As in Abidjan, treatment with organo-mineral fertilizer proved to be the most effective, with a maximum yield of 8.36 ± 0.22 t/ha.

Table 3 Yield of orange-fleshed sweet potato tubers according to fertilization type and location (t/ha)

Treatments	Yields (t/ha)	
	Abidjan	Tiangakaha
OFSP-C	2.57 ± 0.23 [d]	2.22 ± 0.61 [d]
OFSP-MF	5.13 ± 0.12 [c]	3.87 ± 0.29 [c]
OFSP-OF	5.27 ± 1.02 [b]	5.87 ± 0.34 [b]
OFSP-OMF	6.45 ± 0.09 [a]	8.36 ± 0.22 [a]

The values presented correspond to the averages of three replicates (n = 3) ± standard deviation. Within the same column, averages followed by different letters differ significantly according to Duncan's test at the 5% threshold, while those with the same letter do not differ significantly.

OFSP-C: orange-fleshed sweet potato grown without fertilizer; OFSP-MF: orange-fleshed sweet potato grown with mineral fertilizer; OFSP-OF: orange-fleshed sweet potato grown with organic fertilizer; OFSP-OMF: orange-fleshed sweet potato grown with organo-mineral fertilizer.

3.2. Chemical composition of orange-fleshed sweet potato tubers according to treatments and growing areas

Analysis of the chemical composition of orange-fleshed sweet potato (OFSP) tubers grown under different fertilization regimes in Abidjan and Tiangakaha revealed significant variations ($P < 0.05$) for all parameters analyzed (Table 4). These variations reflect the combined influence of fertilizer type and agroecological zone, with differentiated responses between fertilized treatments and the unfertilized control.

The dry matter content of orange-fleshed sweet potato tubers did not vary significantly ($P > 0.05$) between the control and the fertilized treatments, both in Abidjan and Tiangakaha. However, ash content showed significant differences between treatments. In Abidjan, compared to the control (1.87 ± 0.36 %), only the organo-mineral fertilizer (OFSP-OMF) induced a significant increase (2.77 ± 0.15 %), while the mineral (1.80 ± 0.14 %) and organic (2.02 ± 0.02 %) treatments did not result in any significant variation. At Tiangakaha, the ash content of the control (3.60 ± 0.26 %) was significantly increased by all fertilized treatments. The highest values were observed under OFSP-MF (4.03 ± 0.05 %) and OFSP-OMF (3.80 ± 0.10 %).

The lipid content was strongly influenced by mineral fertilization. In Abidjan, the OFSP-MF treatment resulted in the highest value (5.67 ± 1.08 %) compared to 3.54 ± 0.94 % for the control. In Tiangakaha, a similar trend was observed, with 5.38 ± 0.03 % for OFSP-MF compared to 4.96 ± 1.02 % for the control. The organic and organo-mineral treatments showed intermediate values, ranging from 3.65 ± 0.22 % to 5.08 ± 0.25 %.

Protein content showed a clear increase under fertilization, particularly in rural areas. In Abidjan, the organo-mineral treatment (1.07 ± 0.22 %) had a significantly higher content than the control (0.35 ± 0.02 %). Conversely, mineral fertilization led to a significantly lower content (0.17 ± 0.22 %), while the organic treatment (0.40 ± 0.51 %) remained statistically close to the control. At Tiangakaha, fertilized treatments resulted in a significant increase in protein compared to the control (0.95 ± 1.04 %), reaching 1.89 ± 0.61 % with OFSP-MF and 2.04 ± 0.84 % with OFSP-OMF.

Fiber content varied significantly depending on the treatment and area. In Tiangakaha, the control had a content of 6.09 ± 0.05 %, while the organo-mineral treatment achieved the highest value (6.25 ± 1.04 %). The mineral and organic treatments resulted in values lower than those of the control. In Abidjan, the fiber content increased significantly under all treatments compared to the control (4.16 ± 1.00 %), with an increase observed from OFSP-MF (4.22 ± 0.23 %) to OFSP-OMF (4.52 ± 0.02 %).

In contrast, the available carbohydrate content showed a decrease under fertilization, particularly in Tiangakaha. The control sample had a high content of 84.64 ± 0.33 %, while the fertilized treatments had lower values, notably 82.98 ± 0.22 % for OFSP-MF and 83.94 ± 0.05 % for OFSP-OMF. In Abidjan, the highest levels were observed in the control (90.08 ± 0.21 %). All fertilizers resulted in a significant decrease in this parameter, with values ranging from 88.02 ± 0.81 % (OFSP-OMF) to 89.46 ± 1.03 % (OFSP-OF).

Table 4 Biochemical composition of orange-fleshed sweet potatoes (OFSP) according to fertilizer type and location

Parameters	Treatments	Abidjan	Tiangakaha
Dry matter (%)	OFSP-C	91.40 ± 0.20 [a]	90.40 ± 0.17 [a]
	OFSP-MF	91.33 ± 0.35 [a]	90.70 ± 1.10 [a]
	OFSP-OF	91.50 ± 0.46 [a]	90.47 ± 0.06 [a]
	OFSP-OMF	91.30 ± 0.10 [a]	90.83 ± 0.21 [a]
Ash content (%)	OFSP-C	1.87 ± 0.36 [bc]	3.60 ± 0.26 [b]
	OFSP-MF	1.80 ± 0.14 [c]	4.03 ± 0.05 [a]
	OFSP-OF	2.02 ± 0.02 [b]	3.63 ± 0.25 [b]
	OFSP-OMF	2.77 ± 0.15 [a]	3.80 ± 0.10 [ab]
Lipids (%)	OFSP-C	3.54 ± 0.94 [d]	4.96 ± 1.02 [c]
	OFSP-MF	5.67 ± 1.08 [a]	5.38 ± 0.03 [a]
	OFSP-OF	3.84 ± 0.44 [b]	5.08 ± 0.25 [b]
	OFSP-OMF	3.65 ± 0.22 [c]	4.05 ± 0.15 [d]
Protein (%)	OFSP-C	0.35 ± 0.02 [c]	0.95 ± 1.04 [e]
	OFSP-MF	0.17 ± 0.22 [d]	1.89 ± 0.61 [b]
	OFSP-OF	0.40 ± 0.51 [b]	1.12 ± 0.03 [c]
	OFSP-OMF	1.07 ± 0.22 [a]	2.04 ± 0.84 [a]
Fiber content (%)	OFSP-C	4.16 ± 1.00 [d]	6.09 ± 0.05 [b]
	OFSP-MF	4.22 ± 0.23 [c]	5.75 ± 0.84 [c]
	OFSP-OF	4.31 ± 0.32 [b]	5.52 ± 0.22 [d]
	OFSP-OMF	4.52 ± 0.02 [a]	6.25 ± 1.04 [a]
Available carbohydrates (%)	OFSP-C	90.08 ± 0.21 [a]	84.64 ± 0.33 [b]
	OFSP-MF	88.09 ± 0.72 [c]	82.98 ± 0.22 [d]
	OFSP-OF	89.46 ± 1.03 [b]	84.78 ± 0.31 [a]
	OFSP-OMF	88.02 ± 0.81 [d]	83.94 ± 0.05 [c]

The values presented correspond to the averages of three replicates (n = 3) ± standard deviation. Within the same column, averages followed by different letters differ significantly according to Duncan's test at the 5% threshold, while those with the same letter do not differ significantly.

OFSP-C: orange-fleshed sweet potato grown without fertilizer; OFSP-MF: orange-fleshed sweet potato grown with mineral fertilizer; OFSP-OF: orange-fleshed sweet potato grown with organic fertilizer; OFSP-OMF: orange-fleshed sweet potato grown with organo-mineral fertilizer.

3.3. Variation in starch, amylose fractions and sugars in orange-fleshed sweet potato tubers according to fertilizer treatments and production areas

The starch, amylose, amylopectin, total sugar, reducing sugar and simple sugar (glucose, fructose and sucrose) contents of orange-fleshed sweet potato (OFSP) showed significant variations ($P < 0.05$) depending on fertilizer treatments and the agroecological zones studied (Table 5). These variations reflect different responses to fertilizer treatments compared to the unfertilized control, depending on the production area.

At both sites, the starch content was generally higher in tubers from unfertilized control plots. In Abidjan and Tiangakaha, the starch content of the controls (75.07 ± 1.01 g/100 g DM and 76.98 ± 0.78 g/100 g DM, respectively) was significantly higher than that observed under mineral fertilization (72.43 ± 0.51 and 72.69 ± 0.41 g/100 g DM, respectively), organic fertilization (70.05 ± 0.97 and 70.85 ± 0.60 g/100 g DM, respectively) and organo-mineral fertilization (66.79 ± 0.61 and 62.36 ± 0.33 g/100 g DM, respectively), the latter having the lowest values.

The amylose content was also strongly influenced by the treatments. The highest values were observed in the control groups (13.74 ± 0.46 g/100 g DM in Abidjan and 14.59 ± 0.41 g/100 g DM in Tiangakaha). All fertilized treatments resulted in a significant reduction in amylose, with the decrease being more pronounced with the organo-mineral treatment, which recorded the lowest values in Abidjan (7.33 ± 0.26 g/100 g DM) and Tiangakaha (7.54 ± 0.47 g/100 g DM).

In contrast, amylopectin showed less variation among treatments. In Abidjan, values ranged from 61.34 ± 1.46 g/100 g DM in the control to 59.46 ± 0.36 g/100 g DM under organo-mineral fertilization. In Tiangakaha, the highest value was observed in the control (62.39 ± 1.36 g/100 g DM), while the lowest value was recorded under organo-mineral fertilization (54.82 ± 0.47 g/100 g DM).

Total sugars reached maximum levels in the unfertilized control plots in Abidjan (14.65 ± 0.49 g/100 g DM) and Tiangakaha (12.37 ± 0.14 g/100 g DM). Compared to the control, all fertilized treatments led to a significant decrease in total sugars, with the lowest values observed under organo-mineral fertilization in Abidjan (9.19 ± 0.77 g/100 g DM) and Tiangakaha (10.49 ± 0.61 g/100 g DM).

A similar trend was observed for reducing sugars. The highest values were measured in the control samples from Abidjan (7.06 ± 0.11 g/100 g DM) and Tiangakaha (6.46 ± 0.05 g/100 g DM). Compared to the control, fertilized treatments resulted in a significant decrease in reducing sugars, particularly under organo-mineral fertilization, with contents of 4.20 ± 1.08 g/100 g DM in Abidjan and 4.81 ± 0.09 g/100 g DM in Tiangakaha.

With regard to simple sugars, glucose had the highest value in the control in Abidjan (0.13 ± 0.22 g/100 g DM) and Tiangakaha (0.09 ± 0.31 g/100 g DM), while fertilized treatments generally resulted in lower values, particularly under organo-mineral fertilization (0.04 ± 0.31 g/100 g DM in Abidjan and 0.02 ± 0.02 g/100 g DM in Tiangakaha). However, in Tiangakaha, glucose content was significantly higher under organic fertilization (0.12 ± 0.61 g/100 g DM) than in the control.

As for fructose, in Abidjan, it was significantly higher under mineral fertilization (0.10 ± 0.31 g/100 g DM) than in the control (0.03 ± 0.91 g/100 g DM). In Tiangakaha, it reached its maximum value under organic fertilization (0.09 ± 0.01 g/100 g DM), compared to the control (0.06 ± 0.13 g/100 g DM).

In Abidjan, sucrose showed its highest value under organic fertilization (0.11 ± 0.01 g/100 g DM), compared to the control (0.08 ± 0.48 g/100 g DM). In Tiangakaha, sucrose was significantly higher under mineral fertilization (0.16 ± 1.21 g/100 g DM) than in the control (0.08 ± 0.02 g/100 g DM).

Table 5 Starch, amylaceous fractions and sugar contents (g/100 g DM) of orange-fleshed sweet potato tubers according to fertilizer treatments and locations

Parameters	Treatments	Abidjan	Tiangakaha
Starch (g/100 g DM)	OFSP-C	75.07 ± 1.01 [a]	76.98 ± 0.78 [a]
	OFSP-MF	72.43 ± 0.51 [b]	72.69 ± 0.41 [b]
	OFSP-OF	70.05 ± 0.97 [c]	70.85 ± 0.60 [c]
	OFSP-OMF	66.79 ± 0.61 [d]	62.36 ± 0.33 [d]
Amylose (g/100 g DM)	OFSP-C	13.74 ± 0.46 [a]	14.59 ± 0.41 [a]
	OFSP-MF	11.81 ± 0.32 [b]	11.91 ± 0.15 [b]
	OFSP-OF	9.53 ± 0.76 [c]	10.83 ± 0.63 [c]
	OFSP-OMF	7.33 ± 0.26 [d]	7.54 ± 0.47 [d]
Amylopectin (g/100 g DM)	OFSP-C	61.34 ± 1.46 [a]	62.39 ± 1.36 [a]
	OFSP-MF	60.62 ± 0.36 [a]	60.76 ± 0.15 [b]
	OFSP-OF	60.52 ± 1.69 [a]	60.01 ± 0.97 [b]
	OFSP-OMF	59.46 ± 0.36 [a]	54.82 ± 0.47 [c]
Total sugars (g/100 g DM)	OFSP-C	14.65 ± 0.49 [a]	12.37 ± 0.14 [a]
	OFSP-MF	11.27 ± 1.06 [b]	11.32 ± 0.02 [b]
	OFSP-OF	10.23 ± 0.52 [c]	11.16 ± 1.12 [c]
	OFSP-OMF	9.19 ± 0.77 [d]	10.49 ± 0.61 [d]
Reducing sugars (g/100 g DM)	OFSP-OMF	7.06 ± 0.11 [a]	6.46 ± 0.05 [a]
	OFSP-MF	5.41 ± 0.07 [b]	6.23 ± 0.31 [b]
	OFSP-OF	5.18 ± 0.26 [c]	5.31 ± 0.12 [c]
	OFSP-OMF	4.20 ± 1.08 [d]	4.81 ± 0.09 [d]
Glucose (g/100 g DM)	OFSP-OMF	0.13 ± 0.22 [a]	0.09 ± 0.31 [b]
	OFSP-MF	0.06 ± 1.01 [c]	0.07 ± 0.01 [c]
	OFSP-OF	0.10 ± 0.04[b]	0.12 ± 0.61 [a]
	OFSP-OMF	0.04 ± 0.31[c]	0.02 ± 0.02 [d]
Fructose (g/100 g DM)	OFSP-C	0.03 ± 0.91 [b]	0.06 ± 0.13 [b]
	OFSP-MF	0.10 ± 0.31 [a]	0.01 ± 0.08 [c]
	OFSP-OF	0.02 ± 0.61 [b]	0.09 ± 0.01 [a]
	OFSP-OMF	0.02 ± 0.01 [b]	0.07 ± 0.02 [ab]
Sucrose (g/100 g DM)	OFSP-C	0.08 ± 0.48 [b]	0.08 ± 0.02 [b]
	OFSP-MF	0.05 ± 0.02 [bc]	0.16 ± 1.21 [a]
	OFSP-OF	0.11 ± 0.01 [a]	0.76 ± 0.21 [b]
	OFSP-OMF	0.03 ± 0.26 [c]	0.03 ± 0.03 [c]

The values presented correspond to the averages of three replicates (n = 3) ± standard deviation. Within the same column, averages followed by different letters differ significantly according to Duncan's test at the 5% threshold, while those with the same letter do not differ significantly.

OFSP-C: orange-fleshed sweet potato grown without fertilizer; OFSP-MF: orange-fleshed sweet potato grown with mineral fertilizer; OFSP-OF: orange-fleshed sweet potato grown with organic fertilizer; OFSP-OMF: orange-fleshed sweet potato grown with organo-mineral fertilizer.

3.4. Mineral profile of orange-fleshed sweet potato tubers according to fertilizer types and agroecological zones

Analysis of the mineral content of orange-fleshed sweet potatoes (OFSP) revealed significant variations ($P < 0.05$) in potassium, calcium, sodium, phosphorus, magnesium, iron, silicon, manganese, zinc and iodine levels depending on the types of fertilizers and agroecological zones studied (Table 6). These variations reflect the combined influence of fertilization and environmental conditions, with different responses from fertilized treatments compared to the unamended control.

Potassium (K) had the highest levels under fertilization, particularly in rural areas. In Tiangakaha, OFSPs fertilized with mineral fertilizer recorded the highest value (1658.36 ± 4.02 mg/100 g DM), significantly higher than that of the control (933.51 ± 2.02 mg/100 g DM). Compared to the control in Abidjan, which had the lowest content (473.81 ± 0.01 mg/100 g DM), all fertilized treatments resulted in a significant increase in potassium, with values reaching 844.89 ± 0.75 mg/100 g DM under organo-mineral fertilization.

Calcium (Ca) showed contrasting dynamics depending on the area. In Abidjan, the highest content was observed under mineral fertilization (44.50 ± 0.68 mg/100 g DM), compared to the control (26.40 ± 0.07 mg/100 g DM). In Tiangakaha, the unamended OFSPs already had relatively high levels (40.36 ± 0.77 mg/100 g DM), while the fertilized treatments showed moderate variations, with values ranging from 29.18 ± 0.10 to 38.59 ± 0.01 mg/100 g DM.

Sodium (Na) showed maximum levels in the Abidjan control (15.40 ± 0.09 mg/100 g DM). Compared to the control, all fertilized treatments resulted in a significant reduction in sodium content, particularly under organo-mineral fertilization, with a minimum value of 2.46 ± 0.04 mg/100 g DM. In Tiangakaha, sodium was lowest in the control (6.49 ± 0.09 mg/100 g DM), while mineral fertilization resulted in the highest value (9.02 ± 0.22 mg/100 g DM).

Phosphorus (P) was strongly influenced by fertilization, particularly in rural areas. In Tiangakaha, mineral treatment resulted in the highest content (231.62 ± 0.12 mg/100 g DM), a marked increase compared to the control (167.56 ± 0.58 mg/100 g DM). In Abidjan, although the levels were lower overall, fertilized treatments also led to a significant improvement compared to the control (114.63 ± 0.97 mg/100 g DM).

Magnesium (Mg) showed its highest content in organically fertilized OFSPs in Tiangakaha (53.84 ± 0.03 mg/100 g DM), compared to 49.29 ± 0.05 mg/100 g DM for the control. In Abidjan, the levels were lower, with a minimum value observed under organic fertilization (25.76 ± 0.03 mg/100 g DM), compared to the control (37.55 ± 0.05 mg/100 g DM).

Iron (Fe) showed a variable response depending on the area. In Abidjan, mineral fertilization resulted in the highest content (4.63 ± 0.47 mg/100 g DM), higher than that of the control (4.50 ± 0.23 mg/100 g DM). In Tiangakaha, iron levels were generally lower in the control (1.04 ± 0.01 mg/100 g DM), while fertilized treatments, particularly organic and organo-mineral fertilizers, resulted in a significant increase, reaching 4.68 ± 0.57 mg/100 g DM and 3.91 ± 1.07 mg/100 g DM, respectively.

Silicon (Si) levels increased significantly with fertilization in rural areas. In Tiangakaha, organo-mineral treatment resulted in the highest value (19.72 ± 0.35 mg/100 g DM), compared to 3.65 ± 0.73 mg/100 g DM for the control. In Abidjan, silicon levels remained very low under mineral and organo-mineral fertilization (0.01 ± 0.62 mg/100 g DM and 0.01 ± 0.33 mg/100 g DM, respectively).

Manganese (Mn) and zinc (Zn) showed marked increases under mineral fertilization in Tiangakaha. OFSP-MF recorded the highest values for manganese (9.66 ± 1.07 mg/100 g DM) and zinc (4.68 ± 0.02 mg/100 g DM), significantly higher than those of the control (1.02 ± 0.11 mg/100 g DM for Mn and 0.01 ± 0.22 mg/100 g DM for Zn). In Abidjan, these elements had very low levels, regardless of the treatment.

Finally, iodine (I) showed significant variations depending on the treatments and areas. In Tiangakaha, organic fertilization resulted in the highest content (7.23 ± 0.32 mg/100 g DM), a significant increase compared to the control (0.93 ± 0.49 mg/100 g DM). In Abidjan, iodine levels remained low, with the lowest value observed under organic fertilization (0.85 ± 1.00 mg/100 g DM).

Table 6 Mineral content (mg/100 g DM) of orange-fleshed sweet potato tubers according to fertilizer type and location

Parameters	Treatments	Abidjan	Tiangakaha
Potassium (mg/100 g DM)	OFSP-C	473.81 ± 3.01 [d]	933.51 ± 2.02 [d]
	OFSP-MF	531.26 ± 3.51 [c]	1658.36 ± 4.02 [a]
	OFSP-OF	674.12 ± 2.34 [b]	1105.08 ± 5.97 [c]
	OFSP-OMF	844.89 ± 2.75 [a]	1192.56 ± 6.87 [b]
Calcium (mg/100 g DM)	OFSP-C	26.40 ± 0.07 [c]	40.36 ± 0.77 [a]
	OFSP-MF	44.50 ± 0.68 [a]	29.18 ± 0.10 [c]
	OFSP-OF	25.36 ± 0.04 [d]	38.59 ± 0.01 [b]
	OFSP-OMF	29.77 ± 0.32 [b]	38.20 ± 0.11 [b]
Sodium (mg/100 g DM)	OFSP-C	15.40 ± 0.09 [a]	6.49 ± 0.09 [c]
	OFSP-MF	10.72 ± 0.31 [b]	9.02 ± 0.22 [a]
	OFSP-OF	7.93 ± 0.02 [c]	7.65 ± 0.03 [b]
	OFSP-OMF	2.46 ± 0.04 [d]	5.91 ± 0.01 [d]
Phosphorus (mg/100 g DM)	OFSP-C	114.63 ± 0.97 [d]	167.56 ± 0.58 [d]
	OFSP-MF	128.76 ± 0.22 [b]	231.62 ± 0.12 [a]
	OFSP-OF	158.26 ± 1.06 [a]	198.13 ± 1.36 [c]
	OFSP-OMF	126.18 ± 0.55 [c]	208.84 ± 0.62 [b]
Magnesium (mg/100 g DM)	OFSP-C	37.55 ± 0.05 [a]	49.29 ± 0.05 [b]
	OFSP-MF	33.51 ± 0.07 [b]	30.31 ± 0.06 [d]
	OFSP-OF	25.76 ± 0.03 [c]	53.84 ± 0.03 [a]
	OFSP-OMF	33.42 ± 0.03 [b]	43.24 ± 0.01 [c]
Iron (mg/100 g DM)	OFSP-C	4.50 ± 0.23 [b]	1.04 ± 0.01 [d]
	OFSP-MF	4.63 ± 0.47 [a]	1.81 ± 0.31 [c]
	OFSP-OF	2.43 ± 1.01 [d]	4.68 ± 0.57 [a]
	OFSP-OMF	3.68 ± 0.04 [c]	3.91 ± 1.07 [b]
Silicone (mg/100 g DM)	OFSP-C	3.65 ± 0.51 [b]	3.65 ± 0.73 [d]
	OFSP-MF	0.01 ± 0.62 [c]	15.09 ± 0.33 [b]
	OFSP-OF	5.45 ± 0.49 [a]	13.39 ± 0.09 [c]
	OFSP-OMF	0.01 ± 0.33 [c]	19.72 ± 0.35 [a]
Manganese (mg/100 g DM)	OFSP-C	0.01 ± 0.31 [c]	1.02 ± 0.11 [c]
	OFSP-MF	0.01 ± 0.42 [c]	9.66 ± 1.07 [a]
	OFSP-OF	2.56 ± 1.01 [a]	0.01 ± 0.86 [d]
	OFSP-OMF	1.32 ± 0.58 [b]	2.17 ± 0.12 [b]
Zinc (mg/100 g DM)	OFSP-C	0.01 ± 0.31 [c]	0.01 ± 0.22 [d]
	OFSP-MF	0.35 ± 0.03 [b]	4.68 ± 0.02 [a]
	OFSP-OF	2.71 ± 0.20 [a]	3.22 ± 0.42 [c]

	OFSP-OMF	0.01 ± 0.02 [c]	4.46 ± 0.29 [b]
Iodine (mg/100 g DM)	OFSP-C	3.57 ± 0.12 [b]	0.93 ± 0.49 [d]
	OFSP-MF	3.71 ± 0.76 [a]	5.92 ± 0.06 [b]
	OFSP-OF	0.85 ± 1.00 [d]	7.23 ± 0.32 [a]
	OFSP-OMF	2.98 ± 0.08 [c]	4.19 ± 0.04 [c]

The values presented correspond to the averages of three replicates (n = 3) ± standard deviation. Within the same column, averages followed by different letters differ significantly according to Duncan's test at the 5% threshold, while those with the same letter do not differ significantly.

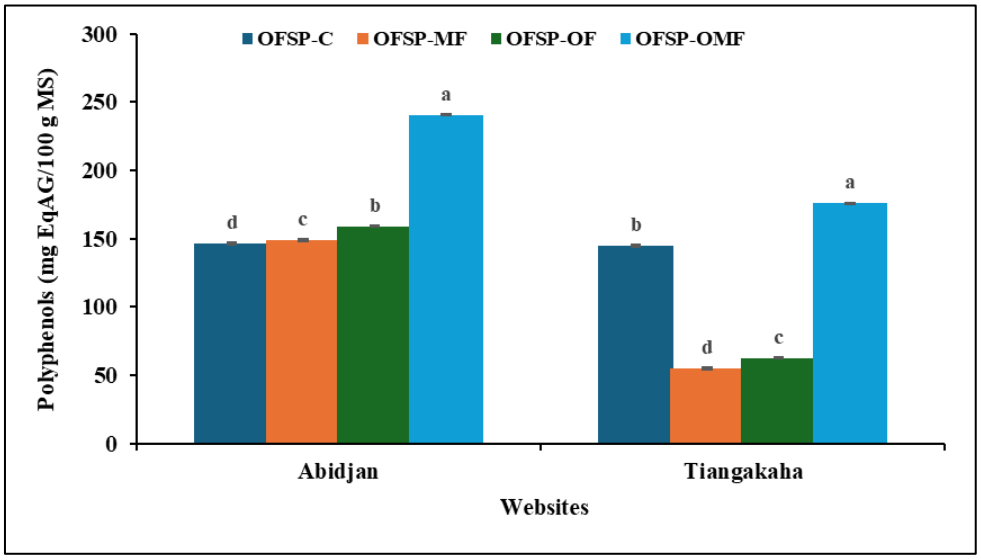
OFSP-C: orange-fleshed sweet potato grown without fertilizer; OFSP-MF: orange-fleshed sweet potato grown with mineral fertilizer; OFSP-OF: orange-fleshed sweet potato grown with organic fertilizer; OFSP-OMF: orange-fleshed sweet potato grown with organo-mineral fertilizer.

3.5. Bioactive compounds in orange-fleshed sweet potato tubers according to fertilizer treatments and locations

Analysis of the bioactive compounds in orange-fleshed sweet potatoes (OFSP) revealed significant differences ($P < 0.05$) depending on the type of fertilizer and location (Abidjan or Tiangakaha).

3.5.1. Total polyphenols

Total polyphenol content varied significantly depending on the treatment and location (Figure 5). In Abidjan and Tiangakaha, the highest levels were recorded under organo-mineral fertilization, where they reached 240.75 ± 0.28 mg EqAG/100 g DM and 176.14 ± 1.98 mg EqAG/100 g DM, respectively, representing a significant increase compared to the controls (146.61 ± 0.58 mg EqAG/100 g DM and 144.98 ± 0.59 mg EqAG/100 g DM, respectively).

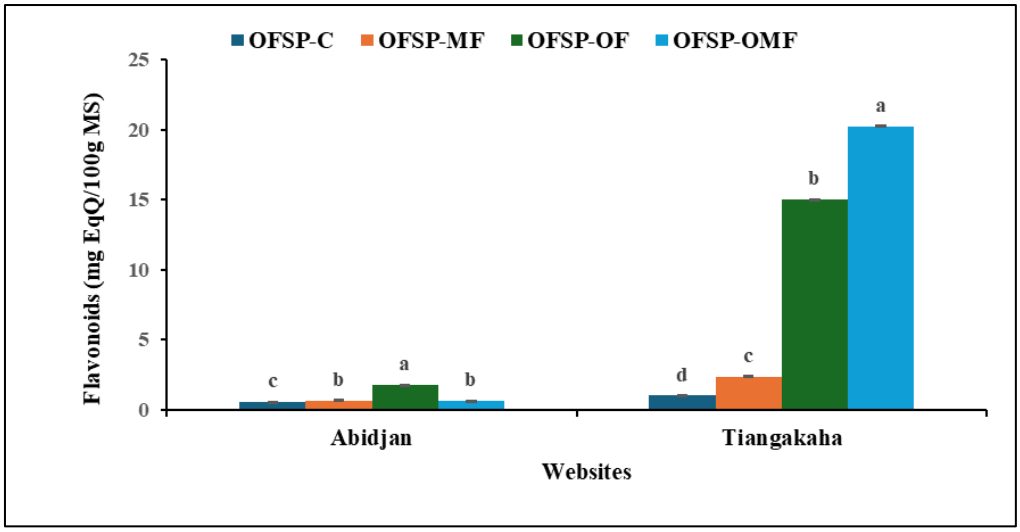


The letters a, b, c, and d are averages of three trials ranked in ascending order with a 95% statistical difference.

Figure 5 Polyphenol content of OFSP tubers according to fertilizers and locations

3.5.2. Flavonoids

The flavonoid content of orange-fleshed sweet potatoes (OFSP) varied significantly depending on the type of fertilizer and location (Figure 6). Compared to the control (0.99 ± 0.01 mg EqQ/100 g DM), all fertilizers induced a notable increase in flavonoids in Tiangakaha, with OMF showing the highest increase (20.24 ± 0.02 mg EqQ/100 g DM). In Abidjan, organic fertilizer (OF) produced the largest increase in flavonoids (1.77 ± 0.02 mg EqQ/100 g DM) compared to the control (0.52 ± 0.01 mg EqQ/100 g DM).

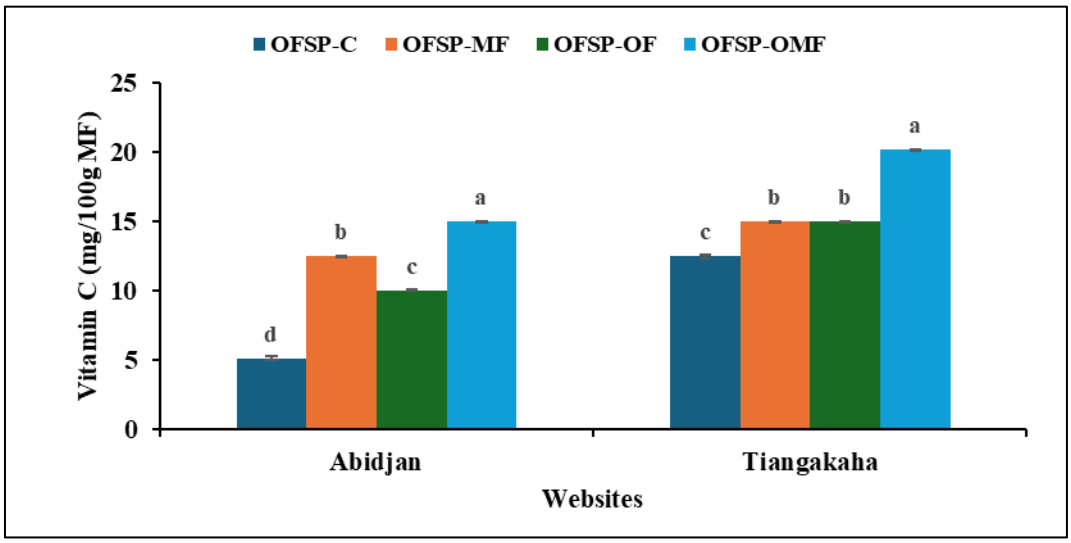


The letters a, b, c, and d are averages of three trials ranked in ascending order with a 95% statistical difference.

Figure 6 Flavonoid content of OFSP tubers according to fertilizers and locations

3.5.3. Vitamin C

The vitamin C content of orange-fleshed sweet potatoes (OFSP) was significantly influenced by the type of fertilizer and the location (Figure 7). The lowest values were observed in the unfertilized controls in both areas, indicating minimal vitamin C accumulation in the absence of fertilizer application. The application of mineral (MF), organic (OF), and organo-mineral (OMF) fertilizers resulted in a significant increase in vitamin C compared to the control. In Tiangakaha, the highest levels were recorded under mineral fertilization (15.04 ± 0.04 mg/100 g MF) and organo-mineral fertilization (12.52 ± 0.03 mg/100 g MF). In Abidjan, these same treatments also improved the levels, although to a more moderate extent (12.52 ± 0.02 mg/100 g MF for MF and 15.02 ± 0.02 mg/100 g MF for OMF).



The letters a, b, c, and d are averages of three trials ranked in ascending order with a 95 % statistical difference.

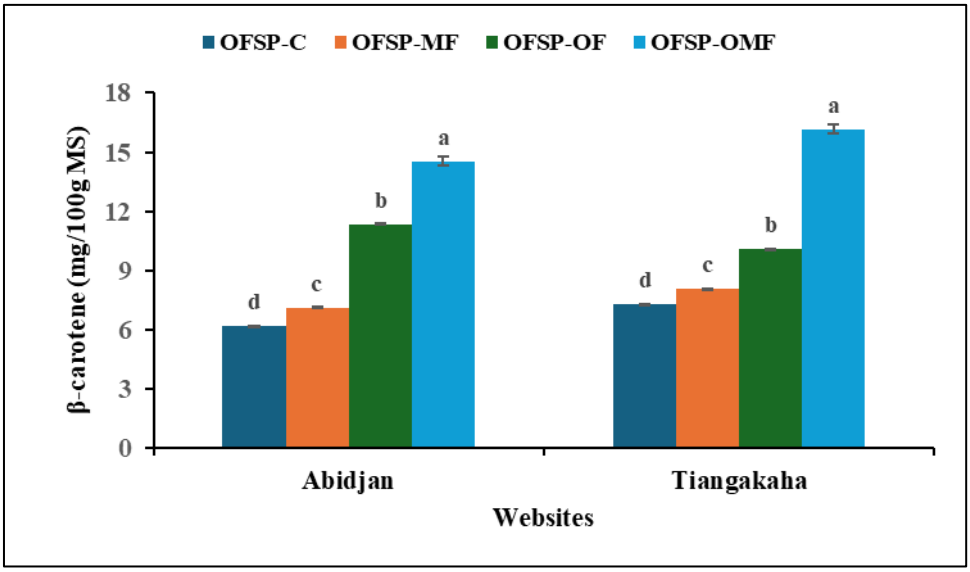
Figure 7 Vitamin C content of OFSP tubers according to fertilizers and locations

3.5.4. β-carotene

The β-carotene content of orange-fleshed sweet potatoes (OFSP) was significantly influenced by the type of fertilizer and the location (Figure 8).

The lowest values were observed in the unfertilized controls in both areas, highlighting the low accumulation of this carotenoid pigment in the absence of fertilizer. The application of organic (OF) and organo-mineral (OMF) fertilizers resulted in a significant increase in β-carotene content compared to the control. In Tiangakaha and Abidjan, the

maximum concentration was recorded under organo-mineral fertilization (16.16 ± 0.22 mg/100 g DM and 14.54 ± 0.03 mg/100 g DM, respectively). Organic fertilization also improved β-carotene content, with 11.35 ± 0.03 mg/100 g DM in Abidjan and 10.08 ± 0.01 mg/100 g DM in Tiangakaha.



The letters a, b, c, and d are averages of three trials ranked in ascending order with a 95% statistical difference.

Figure 8 β-carotene content in OFSP tubers according to fertilizers and locations

3.6. Biochemical characterization and nutritional discrimination of orange-fleshed sweet potatoes (OFSP) using principal component analysis (PCA)

Principal component analysis (PCA) performed on the biochemical, antioxidant, and mineral parameters of orange-fleshed sweet potatoes (OFSP) revealed the main gradients of variation and differentiated the samples according to the type of amendment and the cultivation site. The first two axes, F1 and F2, explain 65.21 % of the total variance (39.85 % for F1 and 25.36 % for F2), providing a clear representation of the nutritional diversity of the tubers.

Axis F1 contrasts an "energy" profile, characterized by high carbohydrate, starch, and glucose content, with a "nutritional" profile, enriched in protein, fiber, and essential minerals such as potassium, zinc, and silicon. Samples from organo-mineral fertilizers are positioned on the positive side of F1, while controls and tubers fertilized with mineral fertilizers are on the negative side, reflecting a higher sugar content.

Axis F2 highlights a gradient of antioxidant compound richness, strongly associated with polyphenols and β-carotene, and inversely correlated with reducing sugars and amylose. OFSP samples treated with organo-mineral amendments have the highest scores on F2, indicating strong antioxidant potential, while the controls and mineral-fertilized samples are on the negative side, dominated by carbohydrates.

The projection of samples onto the F1 × F2 plane distinguishes different nutritional profiles: some combine mineral and antioxidant richness, others have a high sugar and starch content, others are characterized by a high fiber and phenolic compound content, while the controls have a lower nutritional density.

The secondary axes F3 and F4, representing 15.02 % and 8.11 % of the variance respectively, allow for more detailed discrimination based on micronutrition and antioxidant potential, with F3 mainly associated with fructose, calcium, magnesium, and iron, and F4 with vitamin C. Overall, PCA reveals three major nutritional profiles of OFSPs, energy, antioxidant, and mineral, illustrating the combined effect of fertilizer type and production site on their biochemical composition.

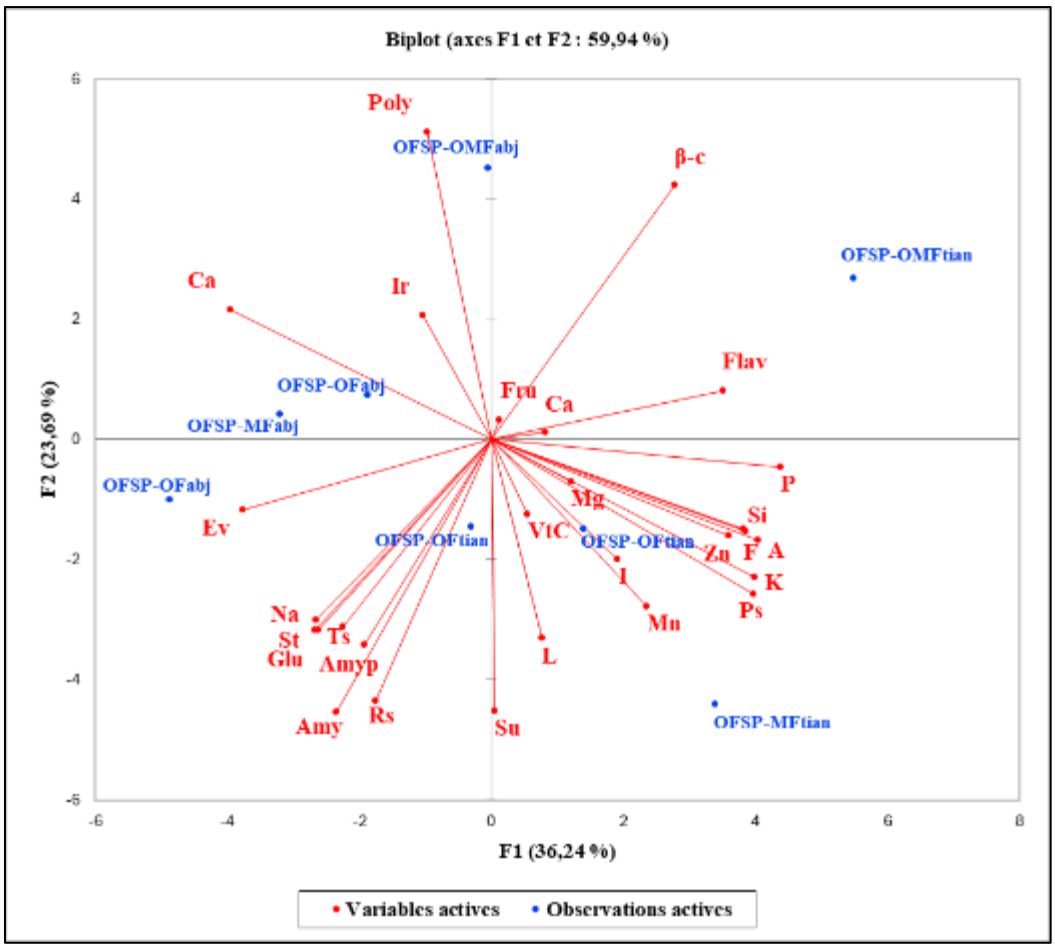


Figure 9 Principal component analysis (PCA) of biochemical variables in orange-fleshed sweet potatoes (OFSP)

A = Ash; L = Lipids; P = Proteins; F = Fibers; Ca = Carbohydrates; Ev = Energy value; St = Starch; Amy = Amylose; Amyp = Amylopectin; Ts = Total sugars; Rs = Reducing sugars; Glu = Glucose; Fru = Fructose; Su = Sucrose; Poly = Polyphenols; Flav = Flavonoids; VtC = Vitamin C; β-c = β-carotene; K = Potassium; Ca = Calcium; Na = Sodium; Ps = Phosphorus; Mg = Magnesium; Ir = Iron; Si = Silicon; Mn = Manganese; Zn = Zinc; I = Iodine.

4. Discussion

The objective of this study was to evaluate the impact of mineral, organic, and organo-mineral amendments on the nutritional quality and mineral density of orange-fleshed sweet potatoes (OFSP) grown in Abidjan and Tiangakaha, in order to identify the most favorable cultivation practices.

Yield increased significantly under all fertilizer treatments compared to the control, highlighting the high responsiveness of OFSPs to nutrient input. In particular, the superior performance observed under organo-mineral fertilization is likely the result of the complementary interaction between the rapid availability of mineral elements and the structuring effects of organic matter on the soil, which improve microbial activity, cation exchange capacity, and water retention [25]. Consequently, this integrated nutrient management promotes leaf expansion, improves photosynthetic efficiency, and facilitates the redistribution of assimilates to reserve roots [26]. In contrast, organic fertilization alone resulted in a more gradual improvement in yield, reflecting the slower rate of mineralization of organic inputs [12]. Consistently, the reduced productivity observed in the control plots highlights the intrinsic nutrient limitations of tropical soils and underscores the need for balanced fertilization strategies.

The dry matter content of orange-fleshed sweet potato tubers (OFSP) was not significantly influenced by the type of fertilization or the growing site, suggesting that this trait depends mainly on the genotype and stage of maturity at harvest. Although organic fertilization improves soil structure and microbial activity, it does not necessarily alter tuber dry matter [27,28]. Furthermore, the minor variations observed between sites likely reflect differences in soil moisture and nutrient uptake efficiency.

The ash content, an indicator of overall mineral richness, varied significantly depending on the type of fertilization, reaching its maximum values under mineral and organo-mineral treatments at Tiangakaha. This trend probably reflects improved soil mineralization and nutrient availability. In addition, organo-mineral fertilizers, by ensuring a balanced and gradual release of nutrients, promote sustained nutrition of tubers and mineral accumulation. These observations corroborate the findings of Asaye et al. [29], who reported positive effects of combined fertilization on the ash and mineral content of tropical root crops.

In terms of lipid content, this was highest under mineral fertilization in Abidjan, probably due to the increased availability of nitrogen and phosphorus, which are essential for lipogenesis and energy metabolism in tuberous tissues [30]. Organic fertilization resulted in more moderate lipid contents, reflecting the slower release of nitrogen, which limits rapid lipogenesis while ensuring a more stable nutrient supply [31]. These differences are of nutritional interest, as lipid content influences both the energy value of tubers and the bioavailability of fat-soluble vitamins.

The protein content was highest in OFSP tubers subjected to organo-mineral fertilization in Tiangakaha. The combination of organic and mineral inputs probably improves nitrogen assimilation and stimulates protein synthesis, including enzymes and structural proteins. These results corroborate those of Dawar et al. [32] and Slameto et al. [33], who reported an increase in protein content in root crops under combined fertilization. Furthermore, the higher levels observed in Tiangakaha may reflect favorable climatic conditions, such as moderate rainfall and high light intensity, which stimulate nitrogen metabolism [34].

Crude fiber content increased significantly under organo-mineral fertilization, especially at Tiangakaha. This enhancement likely reflects intensified cell wall biosynthesis, including cellulose, lignin, and hemicellulose, indicating more complete physiological maturation of tubers. Moreover, potassium and calcium availability are known to support cell wall development, as reported by Shao et al. [35] and Tang et al. [36]. In addition, moderate water stress at Tiangakaha may have contributed to increased lignification.

Fertilization significantly modulated the carbohydrate composition of orange-fleshed sweet potatoes in both agroecological zones. Unfertilized controls exhibited the highest levels of total starch, amylose, total sugars, and reducing sugars, reflecting carbon accumulation under limited nitrogen availability due to restricted growth and protein synthesis [37]. In contrast, organo-mineral and other fertilizers enhanced nitrogen assimilation and vegetative growth, redirecting carbon toward structural and protein compounds at the expense of starch. Notably, the marked reduction in amylose under organo-mineral fertilization suggests regulatory effects on starch biosynthesis enzymes, including ADP-glucose pyrophosphorylase and starch synthases [38], while amylopectin remained relatively stable [39]. The decrease in total and reducing sugars likely reflects mobilization of soluble carbohydrates for cell growth, protein synthesis, and cell wall formation [40,41]. Moreover, resistant starch retained in tubers provides health benefits such as glycemic control, cholesterol reduction, and short-chain fatty acid production [42].

Furthermore, variations observed in bioactive compounds indicate that organic and organo-mineral fertilization promotes the accumulation of polyphenols and flavonoids, probably via the activation of phenylalanine ammonia-lyase and other enzymes in the phenylpropanoid pathway [43]. These compounds enhance the antioxidant capacity of tubers and contribute to the prevention of oxidative stress and metabolic diseases [44]. Overall, these results confirm that the rational intensification of fertilization can improve both the yield and functional value of OFSPs

Organo-mineral fertilization (OMF) significantly increased the β-carotene and vitamin C content of tubers in Abidjan and Tiangakaha, reflecting the synergistic effect of optimal nitrogen and potassium availability on the biosynthesis of carotenoids and water-soluble antioxidants. These results confirm Sun et al. [45], who showed that adequate nutritional status promotes the accumulation of carotenoids in plant tissues. β-carotene, a precursor of vitamin A, plays an essential role in the prevention of hypovitaminosis A [46], while vitamin C improves the absorption of non-heme iron [47]. Furthermore, the simultaneous increase in polyphenols, β-carotene, and vitamin C under FOM, especially in rural areas, highlights the enhanced functional and nutritional value of orange-fleshed sweet potato tubers and their role in reducing micronutrient deficiencies.

Fertilization significantly enriched orange-fleshed sweet potato tubers with essential minerals, with more pronounced responses in Tiangakaha than in Abidjan. Potassium, magnesium, iron, and zinc contents increased compared to the control, reflecting improved soil availability and root absorption efficiency, particularly under organic and organo-mineral fertilization, which optimize both plant nutrition and soil physicochemical properties, such as cation exchange capacity and biological activity. Potassium, the predominant element, peaked under mineral fertilization at Tiangakaha, confirming the high potassium requirement of sweet potatoes for the translocation of assimilates to storage organs [48] and contributing to the regulation of blood pressure and electrolyte balance. Phosphorus, also at its highest under

mineral fertilization, reflects root sensitivity to phosphate inputs [49] and contributes to energy metabolism and starch functionality. Calcium was highest under mineral fertilization in Abidjan, influenced by soil and climate variations and varietal differences, and improves bone health and neuromuscular transmission. Magnesium reached its maximum level under organic fertilization in Tiangakaha, illustrating the positive effect of organic matter on the availability of divalent cations and contributing to glycemic regulation and neuromuscular function. Iron was enhanced by organic fertilization in Tiangakaha and mineral fertilization in Abidjan, suggesting an interaction between the type of amendment and soil and climate conditions, and its enrichment contributes to the prevention of iron deficiency anemia [50]. Finally, zinc and manganese were particularly stimulated by mineral fertilization, while iodine was maximized under organic fertilization, highlighting the role of organic matter in trace element retention [51] and thus reinforcing the functional value of tubers, particularly for thyroid hormone synthesis.

Principal component analysis (PCA) revealed a clear differentiation in the nutritional profiles of tubers depending on the type of fertilization. Organo-mineral treatments were positively associated with protein, fiber, antioxidant compound, and micronutrient content, while control plots were correlated with total carbohydrates and starch. This multivariate structure confirms the synergistic effect of combined amendments and allows for clear classification of samples according to their biochemical characteristics. These results corroborate Zhao et al. [52], who showed that PCA effectively groups sweet potato genotypes or treatments according to their nutritional properties. Thus, the improvement in yield under organo-mineral fertilization is accompanied by an overall improvement in quality, encompassing primary and secondary metabolites.

5. Conclusion

This study showed that fertilization strongly influences the yield and nutritional quality of orange-fleshed sweet potatoes (OFSP) in urban and rural areas of Côte d'Ivoire. Organic-mineral fertilization consistently improved productivity while enriching the tubers with protein, fiber, essential minerals, and bioactive compounds such as β-carotene and polyphenols. Organic and mineral fertilizers also contributed to increased yield and nutritional enrichment, albeit less consistently. As a result, OOR grown with organic-mineral or organic fertilizers have a higher food density, which is crucial for preventing micronutrient deficiencies, particularly vitamin A and essential minerals. These results highlight that the integration of organic and mineral amendments is a sustainable agronomic strategy capable of simultaneously optimizing crop yield and functional quality. Thus, the adoption of fertilizers adapted to local soil conditions is an effective lever for strengthening food security and reducing micronutrient malnutrition in urban and rural communities.

Compliance with ethical standards

Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

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