



Nutritional Study of Four Leafy Vegetables Produced and Sold in the Southern Zone of Brazzaville (Republic of Congo)

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Authors' contributions

This work was carried out in collaboration among all authors. Author MNB did the sample collection, experimental analysis, statistical analysis and wrote the first draft of the manuscript. Author EYJ did the study design, managed the analyses and literature search of the study and wrote the final draft of the manuscript. Author MDMT did the revision and reading of the final draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Generally overlooked by consumers, many local leafy vegetables in the Republic of Congo are considered to be part of the rural way of life and "poor man's food". In order to promote their consumption, this study was carried out to assess the nutrient composition of four leafy vegetables (*Amaranthus hybridus* L, *Basella alba*, *Solanum nigrum* L and *Ipomea batatas* L). The leafy vegetables were collected from two markets and two market garden sites. The pH and the contents in moisture, protein, ash, lipids and minerals (Ca, P, Fe and Mg) were determined using standard analytical methods (Association of Official Analytical Chemists).

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The results indicate that the four leafy vegetables have a pH of between 6 ± 0.03 and 7 ± 0.04 , high moisture content (81.43 ± 0.20 to 94.89 ± 0.12 g/100g FW), high protein content (21.95 ± 0.05 to 32.59 ± 0.07 g/100g FW) and high ash content (13.32 ± 0.05 to 25.78 ± 0.03 g/100g FW). All the vegetables were low in lipids (between 2.73 ± 0.23 and 4.81 ± 0.20 g/100gDW). The investigations also show that the four vegetables studied have high levels of phosphorus ($389.27 \pm 3.23\%$ to 875.22 ± 3.16 mg/100 g DM), iron (70.29 ± 0.15 to 180.06 ± 1.21 mg/100 g DM), calcium (106.78 ± 3.25 to 3404.57 ± 8.07 mg/100 g DM) and magnesium (679.20 ± 2.25 to 2331.25 ± 3.26 mg/100 g DM). In addition, the vegetables collected at the market garden site of the municipal garden had the best a best Ca/P ratio (2.56 to 4.59).

These findings suggest that these leafy vegetables represent a genuine alternative source of protein and especially micronutrients (iron, phosphorus, calcium, magnesium) for human nutrition, health and food safety.

Keywords: Nutritional study; leafy vegetable; *Amaranthus hybridus* L.; *Basella alba*; *Solanum nigrum* L.; *Ipomea batatas* L.; Republic of Congo; minerals.

1. INTRODUCTION

Based on epidemiological studies, healthy eating habits are characterized by a high consumption of plant products, including a wide variety of conventional and exotic vegetables. The consumer choice for conventional vegetables in the daily diet is increasing. Vegetables are the edible part of plants that provide a wide range of micronutrients and phytochemicals [1,2]. They are also rich sources of fiber; dietary fiber is the indigestible part of food that acts to change the nature of the food content. The fibers are known to swell, making defecation more difficult [3]. A number of studies have shown a positive relationship between diets rich in soluble dietary fibers and reduced serum cholesterol and thus a decreased risk of cardiovascular disease [4]. Dietary fiber is also associated with a reduced risk of diabetes, but the mechanism by which this occurs is not well understood [5]. Consumption of vegetables is important because they help to improve general health, protect the body's vital organs, help control weight gain, promote healthy skin and hair, reduce the risk of cardiovascular disease, colorectal cancer, breast cancer, and type 2 diabetes [1,6]. In 1990, the World Health Organization recommended eating at least five servings (about 400 g) of fruit and vegetables per day to prevent cancer and other chronic diseases [7]. In addition, the United States Department of Agriculture (USDA) guidelines (2011) state that an individual should consume at least one cup (~237 g) of raw or cooked vegetables or two cups of raw leafy vegetables per day [8]. Despite the importance of conventional vegetables in improving the nutritional and health status of populations, they still remain inaccessible to the middle class due to their high cost in developing countries, particularly in the Republic of Congo. Therefore, known traditional or indigenous leafy

vegetables such as: *Amaranthus hybridus* L. (*A. hybridus*), *Basella alba* L. (*B. alba*), *Ipomea batatas* L. (*I. batatas*) and *Solanum nigrum* L. (*S. nigrum*), which are accessible and underutilized should be included in a diet diversification strategy to ensure the nutritional and medicinal needs of the populations. These traditional leafy vegetables are accessible to many communities in urban and peri-urban areas and are generally a significant source of micronutrients that contribute to the well-being of the body, and therefore a solution to problems of malnutrition, food security and nutrition [9]. Traditional (or indigenous) leafy vegetables, as opposed to exotic vegetables from temperate countries, are important sources of fiber, vitamins (especially vitamins A, B and C), proteins and carbohydrates [10]. Due to their taste and wide availability, traditional leafy vegetables could meet the essential nutritional and medicinal needs of the populations. For According to the studies by [11-13], the amaranth leaves for example, contain ample protein, including lysine and methionine, minerals, dietary fiber, bioactive pigments, and phytochemicals, including betacyanins and carotenoids betaxanthins, chlorophylls, ascorbic acids and β -carotene, phenolic profiles with sufficient antiradical activity. Amaranths are used as folk medicine, especially antimicrobial, anticancer, antidiabetic, antimalarial, and snake antidotes.

Sweet potato (*Ipomoea batatas*) leaves provide a dietary source of vitamins, minerals, antioxidants, dietary fiber, and essential fatty acids. Bioactive compounds contained in this vegetable play a role in health promotion by improving immune function, reducing oxidative stress and free radical damage, reducing cardiovascular disease risk, and suppressing cancer cell growth [14]. *Solanum nigrum* generally known as black

nightshade is one of the traditional vegetables for which several authors have reported the importance in reducing malnutrition problems by providing the required amounts of protein, minerals and vitamins to the human body [15]. However, despite their advantages, these leafy vegetables are under-exploited in the Republic of Congo due to the lack of scientific data on their biochemical characterization. This limits their use in the fight against protein-calorie malnutrition and chronic diseases such as cardiovascular disease, diabetes and cancer. The aim of this study was to assess the nutritional composition of four leafy vegetables collected from two market sites and two market gardening sites in the southern part of Brazzaville. The nutritional composition, which includes proximate analyses (moisture, ash, protein and fat), and minerals composition (Ca, P, Fe and Mg), were evaluated. The data on nutritional composition from the present study, will contribute to expanding the nutrient databases and are beneficial for future research on nutrition and human health.

2. MATERIELS AND METHODS

2.1 Plant Materials

The plant material for the present study consisted of the leaves of amaranth (*Amaranthus hybridus*), spinach (*Basella alba*), sweet potato

(*Ipomea batatas*) and black nightshade (*Solanum nigrum*).

2.2 Methods

2.2.1 Plant sample collection

The sampling was carried out in the city of Brazzaville (South Zone) in the Republic of Congo. Samples were collected from two market garden production sites (Jardin municipal and Agri-Congo mayanga) and two markets (Marché Total and Marché PK). At each site, the fresh leafy vegetables were collected from producers and vendors. Identical varieties were put together to form a batch. The samples were placed in airtight containers and taken to the laboratory for analysis.

2.2.2 Preparation of the samples

Once transported to the laboratory, the leaves of these vegetables were thoroughly washed with water to remove dirt and drained. The leaves were weighed using a precision balance and then oven dried at a temperature of 60°C. The dry matter obtained after drying was ground using a porcelain mortar and the powder obtained was used for the various chemical analyses.



Photo 1. Amaranth (*Amaranthus hybridus*)



Photo 2. Spinach (*Basella alba*)



Photo 3. Sweet potato (*Ipomea batatas*)



Photo 4. Black nightshade (*Solanum nigrum*)

2.2.3 Chemical analysis

2.2.3.1 Determination of the moisture content

The moisture content was determined according to the Standard Association of Official Analytical Chemists method [16,17], the principle of which is based on the loss of mass of the sample to a constant mass by steaming at 70°C for 72 h. The weights of the samples were registered on a precision balance of the brand OHAUS.

2.2.3.2 Determination of pH

After homogenization for 30 minutes, the mixture was filtered and the filtrate was collected in an Erlenmeyer flask. The pH was read directly from the filtrate using pH paper.

2.2.3.3 Determination of lipid content

The lipid content was determined by the Soxhlet method described by [16,17]. The extraction of the oils is obtained by using hexane in a Soxhlet type extractor. After extraction of the fat, the flask containing the solvent-fat mixture was recovered and the separation of the solvent from the oil was carried out by drying in an oven at 50°C. the difference in weight gives the lipid content of the sample.

2.2.3.4 Determination of protein content

The protein content was determined from the determination of total nitrogen in dry matter, according to the Kjeldhal method [16,17]. The nitrogen in dry matter is determined after mineralization with sulfuric acid in the presence of a selenium catalyst. The ammonia was then distilled in an excess of sodium hydroxide and recovered in boric acid using bromocresol green and methyl red as an indicator. The nitrogen was titrated with sulphuric acid until the indicator turned from green to pink. The calculated nitrogen content from the samples in percent was converted to crude protein by multiplying by a factor of 6.25.

2.2.3.5 Determination of ash content

Total ash was determined by according to the AOAC procedure [16,17], which consists of incinerating the dry matter in a muffle furnace at a temperature of 550°C for 6 h. The ash content was expressed on dry matter basis and reported as a percentage.

2.2.3.6 Determination of mineral content

After mineralization of the different samples in the furnace at 450°C, the ash was recovered, moistened with water and concentrated

hydrochloric acid, then the mineral elements (P, Fe, Ca and Mg) were determined using methods described by [18].

The Phosphorus (P) content was assayed by the cold colorimetric method using Murphy and Riley's reagent.

The iron (Fe) content was determined using colorimetric Spectro colorimeter.

The calcium (Ca) and magnesium (Mg) content were determined using the complexometric method. After plotting the calibration lines for each element, the concentrations read for the sample and blank were [18].

2.2.3.7 Data analysis and processing

Statistical analysis was carried out using IBM SPSS version 22.0 software. An analysis of variance was carried out and the comparison of the means of the different parameters studied was carried out by the Newman-Keuls test at the 5% threshold.

3. RESULTS AND DISCUSSION

3.1. Chemical Composition of Four Vegetables Collected in Four Sites

This Table 1 shows the moisture, lipid, protein and ash contents of the four leafy vegetables collected from four sites.

The results presented in this table show that the moisture content of *A. hybridus* from Agri-Congo Mayanga (89.28 ± 0.17 g/100g FW) was higher and significantly different ($P < 0.05$) than those from the municipal garden (86.28 ± 0.19 g/100gFW), the PK market (85.71 ± 0.05 g/100g) and the total market (81.43 ± 0.20 g/100g FW). The moisture content of *B. alba* (Table 1) from the municipal garden (94.89 ± 0.12 g/100g FW) was higher and significantly different ($P < 0.05$) than the moisture content of *B. alba* from the total market. The moisture content of the species collected at Agri-Congo Mayanga, at the total market and at the PK market, there was no significant difference ($P > 0.05$) between *B. alba* from the total market (88.84 ± 0.07 g/100g FW) and the PK market (88.17 ± 0.09 g/100g FW).

The moisture content of *I. batatas* leaves from the municipal garden (91.56 ± 0.02 g/100g MF) was higher and significantly different ($P < 0.05$) than that of *I. batatas* from Agri-Congo Mayanga (85.94 ± 0.21 g/100g FW), the total market (83.13 ± 0.25 g/100g FW) and PK market

(81.78±0.20 g/100g FW); there is no significant difference ($P > 0.05$) between *I. batatas* from the total market (83.13±0.25 g/100g FW) and PK market (81.78±0.20 g/100g FW). This table shows that there is no significant difference ($P > 0.05$) between the moisture content of *S. nigrum* from the municipal garden (85.92±0.05 g/100g FW) and from the total market (85.31±0.13 g/100g FW); between the moisture content of *S. nigrum* from the Agri-Congo Mayanga site (88.54±0.02 g/100g FW) and from the PK market (88.92±0.08 g/100g FW). These moisture values are within the ranges generally for cultivated and commonly consumed leafy vegetables. The moisture content of the leafy vegetables in this study is directly related to the maturity of the plant. The high moisture content indicates that the four leafy vegetables are perishable commodities and therefore require appropriate storage as they are susceptible to degradation by microbial and enzymatic activity [19]. These values were similar to those obtained by [20] for *Lagenaria siceraria* (87.07%) in Brazzaville (R. Congo), by [19] for twelve species of leafy vegetables consumed in Thailand, by [21] for the leaves of *Ipomoea batatas* L. (86.42 ± 0.26%), *Spinacia oleracea* (93.75 ± 0.12%), *Manihot esculenta* Crantz (78.02 ± 0.25%) and *Colocasia esculenta* L. (87.88 ± 0.32%). They are also close to the values presented by [22] for six leafy vegetables, namely *Spinacia oleracea* (92.1%), *Amaranthus gangeticus* (85.7%), *Trigonella foenum graecum* (86.1%), *Moringa oleifera* (75.9%), *Brassica*

oleracea var. *capitata* (91.9%) and *Chenopodium album* (89.6%). The results obtained in this study were similar to the results obtained for *A. tricolor* and *sweet potato* leaves by [12] and [23] respectively.

For lipid content (Table 1), the four vegetables analyzed showed low values in all sites ranging from 2.73 ± 0.23 g/100g DW (*A. hybridus* from the PK market) to 4.81 ± 0.20 g/100g DM (*S. nigrum* from the PK market). There was no significant difference ($P > 0.05$) between *A. hybridus* from the municipal garden (3.76±0.05 g/100g DW), the total market (3.64±0.05 g/100g DW) and the PK market (3.74±0.05 g/100g DW). The lipid contents of *B. alba* from the market garden sites Jardin Municipal (4.20±0.06 g/100g DW) and Agri-Congo Mayanga (4.41±0.05 g/100g DW) were not significantly different ($P > 0.05$), as well as from the total market (3.90±0.06 g/100g DW) and PK (3.88±0.06 g/100g DW). The lipid contents of *I. batatas* leaves from the municipal garden, the total market and Agri-Congo Mayanga were not significantly different ($P > 0.05$), with values of 4.65±0.04; 4.43±0.02 and 4.30±0.02 g/100g DW respectively. The lipid contents of *S. nigrum* leaves from two markets were statistically identical ($P > 0.05$), and higher than those from the market garden sites which were statistically different ($P < 0.05$). The lipid contents of the analyzed leafy vegetables are very low, these results confirm the conclusions of several authors which showed that vegetables are low in lipids [24]. Nevertheless, it is

Table 1. Chemical composition (%) of four vegetables collected in four sites

Vegetable	Parameters	Municipal garden	Total market	Agri-Congo Mayanga	PK market
<i>A. hybridus</i>	Moisture*	86,28±0,19 ^b	81,43±0,20 ^c	89,28±0,17 ^a	85,71±0,05 ^b
	Fat	3,76±0,05 ^b	3,64±0,05 ^b	3,74±0,05 ^b	2,73±0,07 ^a
	Protein	27,83±0,54 ^a	27,12±1,53 ^b	21,94±0,56 ^c	24,03±0,74 ^c
	Ash	20,49±0,23 ^c	23,08±0,25 ^a	21,41±0,18 ^b	19,99±0,21 ^d
<i>B. alba</i>	Moisture	94,89±0,12 ^a	88,84±0,07 ^c	92,93±0,23 ^b	88,17±0,09 ^c
	Fat	4,20±0,06 ^a	3,90±0,06 ^b	4,41±0,05 ^a	3,88±0,06 ^b
	Protein	29,36±0,71 ^a	24,62±1,07 ^c	23,69±0,73 ^c	27,43±0,88 ^b
	Ash	19,38±0,34 ^d	22,39±0,38 ^c	23,41±0,35 ^b	25,78±0,30 ^a
<i>I. batatas</i> L	Moisture	91,56±0,02 ^a	83,13±0,25 ^c	85,94±0,21 ^b	81,78±0,20 ^c
	Fat	4,65±0,04 ^a	4,43±0,02 ^a	4,30±0,02 ^a	3,65±0,06 ^b
	Protein	26,50±0,15 ^b	23,03±0,66 ^c	29,18±1,20 ^a	26,29±0,49 ^b
	Ash	19,31±0,58 ^b	10,82±0,31 ^d	20,22 ±0,24 ^a	13,97±0,26 ^c
<i>S. nigrum</i> L	Moisture	85,92±0,05 ^b	85,31±0,13 ^b	88,54±0,02 ^a	88,92±0,08 ^a
	Fat	4,41±0,05 ^b	4,81±0,05 ^a	3,54±0,03 ^c	4,77±0,05 ^a
	Protein	32,58±0,35 ^a	28,77±0,25 ^c	30,89±0,35 ^b	32,51±0,31 ^a
	Ash	13,59±0,29 ^d	23,62±0,31 ^a	18,01±0,25 ^c	19,17±0,27 ^b

The contents with the different alphabetical letters on the same line are significantly different ($P < 0.05$); * Moisture content was expressed in g/100 g FW

necessary to mention that a diet providing 1-2% of energy in the form of fat is considered sufficient for humans, as exaggerated fat consumption leads to diseases such as stroke, cancer and atherosclerosis [24]. Thus, the consumption of these vegetables can be recommended to people suffering from these diseases. The lipid contents of the analyzed vegetables are lower compared to *Amaranthus cruentus* (15.88%), *Amaranthus viridis* (8.56%) and *Solanum nigrum* (15.06%) analyzed by [25] in Nigeria. However, the lipid contents of *I. batatas* and *A. hybridus* (0,39±0,27-0,53±0,35g/100g FW) in relation to fresh matter obtained in this study were similar to those reported by [23] and [12].

For protein content (Table 1), the values obtained for the four leafy vegetables analyzed in the four sites are very high, ranging from 21.94±0.56 g/100g DW (Agri-C Mayangua) - 27.83±0.54 g/100g DW (Garden municipal) for *A. hybridus*; 23.69±0.73 g/100g DW (Agri-C Mayangua)-29.36±0.71 g/100g DW (Garden municipal) for *B. alba*; 23.03±0.66 g/100g DW (Total market)-29.18±1.20 g/100g DW (Garden municipal) for *I. batatas* and 28.77±0.25 g/100g DW (Total market)-32.58±0.35 g/100g DW (Garden municipal) for *S. nigrum*. For all the vegetables analyzed, except for the *I. batatas* leaves, the protein content was higher in the municipal garden. The results (Table 1) show, on the one hand, no significant difference ($P > 0.05$) between the protein content of *A. hybridus* and *B. alba* from the market gardening site (Agri-C mayanga) and the PK and total markets respectively, and on the other hand, between the protein content of *I. batatas* and *S. nigrum* leaves from the market gardening site (municipal garden) and the PK market. This indicates that the *A. hybridus* and *B. alba* leaves sold respectively at the PK market and Total could have come from the market garden site (Agri-C mayanga). While the *I. batatas* and *S. nigrum* sold at the PK market could come from the municipal garden. High protein content of the analyzed vegetables could be explained by the use of nitrogen fertilizer (NPK) and these results confirm those of [26] who stated that the use of nitrogen fertilizer (NPK) during production influences the protein content of leafy vegetables. These results show that the leafy vegetables analyzed are a good source of protein, which confirms the work of [27,28] who stated that "tropical leafy vegetables are rich in protein and can contribute to food security for poor people". This is because protein is a nutrient that can renew cells and is

necessary for the growth of children [21]. The protein contents of the analyzed vegetables were higher than those of five wild vegetable species (4.55±0.29 - 21.45± 0.23%) consumed in Bangladesh [28], three leafy vegetables consumed in Malawi [29], namely *Amaranthus* spp (18.09±0.19), *Bidens pilosa* (19.04±0.33%) and *Galinsoga parviflora* (15.83±0.19%) and *Amaranthus cruentus* (11.32%), *Amaranthus viridi* (8.56%), *Solanum nigrum* (15.06%) consumed in Nigeria [25] and five leafy vegetables (4.78±0.01- 10.75±0.24%) consumed in the Marahoué region (Côte D'ivoire) [30]. However, our results are lower than those obtained by [31] for amaranth (37.21%), *celosia* (34.25%) and nightshade (37.5%) in Côte d'Ivoire.

Regarding ash content (Table 1), the leafy vegetables analyzed showed high ash contents ranging from 19,99±0,21 g/100g DW (PK market)- 23,08±0,25 g/100g DW (Total market) for *A. hybridus*; 19,38±0,34 g/100g DW (Garden municipal)- 25,78±0,30 g/100g DW (Agri-C mayangua) for *B. alba*; 10,82±0,31 g/100g DW (Total market)- 20,22 ±0,24 g/100g DW (Agri-C mayangua) for *I. batatas* and 13,59±0,29 g/100g DW (Garden municipal) -23,62±0,31 g/100g DW (Total market) for *S. nigrum*. For the four vegetables analyzed, there is a significant difference ($P < 0.05$) from one collection site to another (Table 1). The ash contents of *Ipomea batatas* leaves obtained in this study at the two sales sites were similar to those reported by [23]. However, the ash contents at the two market garden sites were higher than those reported by the same authors [23]. The ash content is an indicator of the mineral content of a plant material [30], which makes it possible to say that these vegetables studied are therefore rich in mineral elements and therefore remain a significant source of mineral elements, which are important components of the human diet, as they serve as cofactors in many physiological and metabolic processes [21].

3.2 The Hydrogen Potential (pH) of the Four Leafy Vegetables

The pH values of the four leafy vegetables collected at four sites are presented in Table 2.

The results show that all the leafy vegetables analyzed were close to neutrality pH, there was no significant difference between the same vegetable from one site to another. The values were between 6 ± 0.03 and 7 ± 0.04 .

Table 2. pH values of four leafy vegetables collected at four sites

Vegetables	Garden municipal	Total market	Agri-Congo mayanga	PK market
A. hybridus	6,75±0,05 ^a	7±0,05 ^a	7±0,05 ^a	7±0,05 ^a
B. alba L	7±0,04 ^a	6,91±0,03 ^a	6,25±0,04 ^a	7±0,04 ^a
I. batatas L	6,16±0,03 ^a	6±0,03 ^a	6±0,03 ^a	6,68±0,03 ^a
S. nigrum L	6,33±0,07 ^a	6,78±0,06 ^a	6,71±0,06 ^a	6,68±0,06 ^a

Values with the same alphabetical letters on the same line are statistically identical ($p > 0.05$)

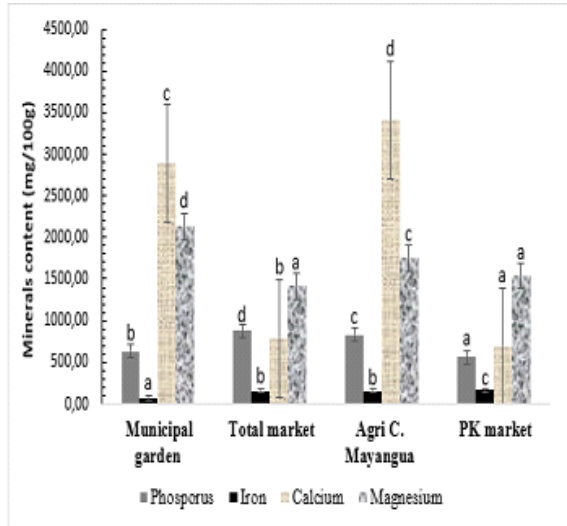


Fig. 1. Minerals content (mg/100g dry weight) of *A. hybridus* L of four sites

According to the mineral, the bars with different letters are significantly different at $p < 0.05$

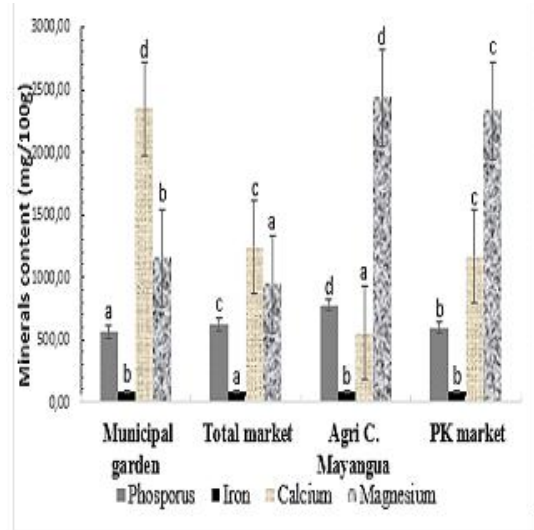


Fig. 2. Minerals content (mg/100g dry weight) of *B. alba* L of four sites

According to the mineral, the bars with different letters are significantly different at $p < 0.05$

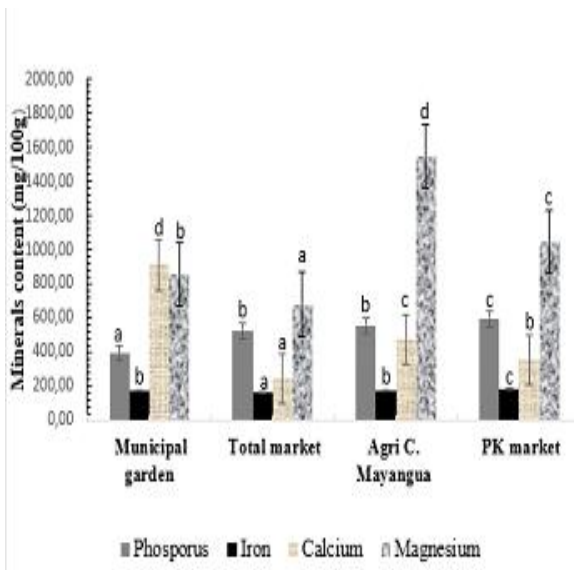


Fig. 3. Minerals content (mg/100g dry weight) of *I. batatas* L of four sites

According to the mineral, the bars with different letters are significantly different at $p < 0.05$

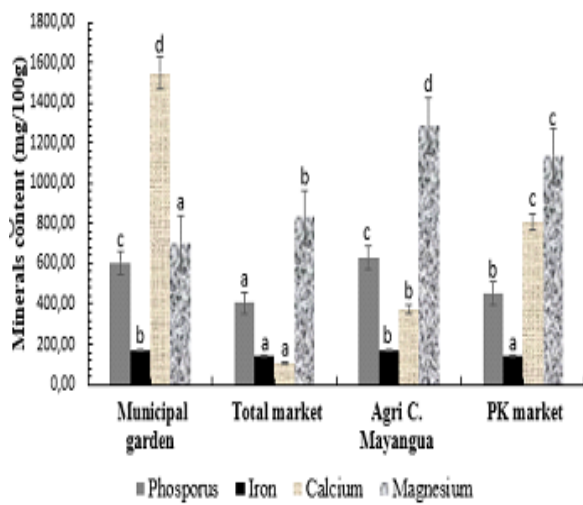


Fig. 4. Minerals content (mg/100g dry weight) of *S. nigrum* of four sites

According to the mineral, the bars with different letters are significantly different at $p < 0.05$

The results obtained in this study are almost similar to those of [32] for lettuce (6.64 ± 0.78 to 6.89 ± 0.98) and [21] for spinach culture (6.22), *Ipomea batatas* (6.56) and cassava leaves (6.37) and [33] for *B. alba* (5.92 ± 0.01) consumed in Southern Côte d'Ivoire. The pH of these leafy vegetables analyzed could favor the growth of micro-organisms; as most micro-organisms grow at pH close to neutrality [34].

3.3 Mineral Composition of the Four Leafy Vegetables

The contents of macroelements (P, Ca and Mg) and the microelements (Fe) in the leafy vegetable analyzed vary between the sites and the results were shown on Figs. 1,2,3 et 4. Generally, the results indicate that the vegetables are good sources phosphorus, calcium, magnesium and iron.

3.3.1 Phosphorus content

For *A. hybridus* (Fig. 1), the phosphorus content, the values obtained were significantly different ($P < 0, 05$) from one site to another, the phosphorus content of *A. hybridus* from the total market (875.22 ± 3.16 mg/100g DW) is higher than those of Agri. C. Mayanga (834.32 ± 5.07 mg/100g DW), the municipal garden (630.27 ± 3.15 mg/100g DW) and the PK market (559.22 ± 2.02 mg/100g DW). In the case *B. alba* leaves (Fig. 2), the phosphorus content varied significantly ($P < 0.05$) from one site to another, it was higher in *B. alba* from the Agri-C mayanga market garden site (777.81 ± 4.06 mg/100g DW). Phosphorus content in *B. alba* leaves from the municipal garden, total market and PK market were 558.95 ± 4.05 , 624.87 ± 4.05 and 595.35 ± 4.05 mg/100g DW respectively. For *I. batatas* leaves (Fig. 3), the phosphorus content was higher at the PK market (594.35 ± 3.21 mg/100g DW) than at the total market (527.78 ± 3.25 mg/100g DW), Agri-C mayanga market garden (558.10 ± 3.25 mg/100g DW) and municipal garden (389.26 ± 3.23 mg/100g DW). There were no significant differences between *I. batatas* from the total market and the Agri-C mayanga market garden site ($P > 0.05$). For *S. nigrum* leaves (Fig. 4), the phosphorus contents of two market garden sites were higher than those of the markets, i.e. 604.93 ± 2.21 mg/100g DW for the municipal garden, 630.36 ± 2.15 mg/100g DW for Agri C. mayanga, 452.21 ± 2.23 mg/100g DW for the PK market and 406.48 ± 2.25 mg/100g DW. There were no significant differences between the phosphorus contents of

S. nigrum leaves from two market garden sites ($P > 0.05$).

Phosphorus contents of *I. batatas* leaves in this study are in the range of results obtained by [23] on leaves of 40 sweet potato varieties ($131.1 \pm 3.3 - 2639.8 \pm 1.3$ mg/100 g DW). Phosphorus contents in this study are higher than those obtained by [35] for *Haematostaphis harteri* (340mg/100 g) in Togo and by [36] for amaranth crop (86.19mg/100 g). However, these results are lower than those obtained by [37] for *C. rubens* (1409mg/100g) and *C. crepidioides* (1039.2mg/100g) and by [31], for African nightshade leaves (2229mg/100g), for *Cleome gynandra* (2223mg/100g) and for *Corchorus olitorius* (2262mg/100g).

The leafy vegetables studied are a good source of phosphorus, an essential mineral required for cell structure, signaling, energy transfer and other important functions. The main function of phosphorus is the formation of bones and teeth [38]. It is also involved in the formation of basic molecules such as nucleic acids (DNA and RNA), adenosine triphosphate (ATP) and membrane phospholipids [38].

3.3.2 Iron content

With regard to the leaves of *A. hybridus* (Fig. 1), the iron content varies significantly between the sites, however there is no significant difference between *A. hybridus* from the total market (151.53 ± 0.16 mg/100g DW) and from Agri. C. Mayanga (156.31 ± 0.15 mg/100g DW). The iron content of *A. hybridus* from the PK market (161.04 ± 0.12 mg/100g DW) was the highest and that of the municipal garden (70.29 ± 0.15 mg/100g DW) was the lowest. These values are higher compared to those found by [25] for *Amaranthus cruentus* (7.52 mg/100g) and *Amaranthus viridis* (4.28 mg/100g), by [31] for *Amaranthus* (56 mg /100 g DW) [39].

For *B. alba* leaves (Fig. 2), the iron contents were statistically identical in the municipal garden, Agri C. mayanga and PK market, with respective values of 91.92 ± 2.25 mg/100g DW; 91.69 ± 5.03 mg/100g DW and 91.21 ± 0.25 mg/100g DW. The iron content of *B. alba* leaves in the total market was at 90.28 ± 2.33 mg/100g DW. These values were higher than the value of *B. alba* leaves (63.33 ± 0.01 mg/100g DW) consumed in the southern Ivory Coast reported by [33].

In the case of *I. batatas* leaves (Fig. 3), the iron contents were statistically identical between two market garden sites: 171.71 ± 1.23 mg/100g DW for the municipal garden and 170.88 ± 1.2 mg/100g DW for Agri-C mayanga. The iron contents of *I. batatas* leaves from the total and PK markets were 164.33 ± 1.20 and 180.06 ± 1.21 mg/100g DW respectively. These values were higher compared to those found by [23]: 1.92 ± 0.00 to 21.77 ± 0.33 mg/100gDW. For *S. nigrum* leaves (Fig. 4), the iron contents of the municipal garden (168.87 ± 6.65 mg/100g DM) and Agri C. mayangua (169.34 ± 4.31 mg/100g DW) were statistically identical ($P > 0.05$). The iron contents of *S. nigrum* leaves or black nightshade from the total and PK markets were 143.33 ± 5.61 and 142.22 ± 2.15 mg/100g DW respectively; there was no significant difference ($P > 0.05$). The values for black nightshade in the present study are higher compared to those found by [40] for black nightshade (19.36 mg/100g to $153, 61$ mg/100g) produced in Cameroon. The iron content of the leafy vegetables studied were higher than the recommended dietary requirement for men (1.37 mg/day) and women (2.94 mg/day) [41]. The high iron content in the vegetables analyzed in this study is essential for consumers, as iron is an essential element for most life forms on earth, including humans. It is responsible for the formation of hemoglobin, myoglobin and cytochrome, regulates body temperature, muscle activity, catecholamine metabolism, thyroid function, the immune system, brain development and function [42].

3.3.3 Calcium content

For *A. hybridus* (Fig. 1), the calcium content of the Agri-C Mayanga market garden site (3404.57 ± 8.07 mg/100g DW), was higher than those of the municipal garden, the total market and the PK market, with values of 2895.24 ± 5.25 ; 787.72 ± 7.26 and 693.80 ± 7.12 mg/100g DW respectively. There was a significant difference ($P < 0, 05$) between the calcium contents from one site to another. The values of *A. hybridus* from two market garden sites (Municipal garden and Agri C. mayanga) in the present study are higher than the calcium content obtained by [25] for *Amaranthus cruentus* (2380 mg/100g) and *Amaranthus viridis* (1450 mg/100g) consumed in Nigeria. For *B. alba* leaves (Fig. 2), the calcium content was high at the municipal garden (2347.83 ± 8.05 mg/100g DW). The calcium contents of *B. alba* leaves collected from the total (1240.43 ± 6.15 mg/100g DM) and PK (1161.75

± 8.57 mg/100g DW) markets were statistically identical ($p > 0.05$) and the lowest content was recorded at the Agri-C mayanga site (553.42 ± 4.46 mg/100g DW). These values are lower than the value obtained by for *B. alba* (4136.77 ± 34.00) s consumed in Southern Côte d'Ivoire [33]. For the leaves of *I. batatas* (Fig. 3), the calcium contents varied significantly from one site to another. They are 911.08 ± 6.23 mg/100g DW for the municipal garden; 240.72 ± 3.25 mg/100g DW for the total market; 473.89 ± 5.65 mg/100g DW for Agri C. Mayanga and 357.01 ± 5.21 mg/100g DW for Agri C. Mayanga. In this study, the calcium contents of *I. batatas* leaves are within the range of the results of [23] which found values between 229.7 ± 0.4 to $1958.1 \pm 24.$ mg/100 g DW. For the leaves of *S. nigrum* (Fig. 4), the calcium contents varied significantly ($P < 0.05$) between sites. The highest calcium content was recorded at the municipal garden (1548.18 ± 5.21 mg/100g DW) and the lowest was at the total market (106.78 ± 3.28 mg/100g DW). Calcium contents at the level Agri C. mayanga site and PK market were 373.84 ± 2.35 and 807.21 ± 4.23 mg/100g DW respectively. The calcium content values of *S. nigrum* in the present study are lower than the calcium content of *Solanum nigrum* (2710 mg/100g) reported by [25] consumed in Nigeria. All results of this study are higher than the calcium contents (9.00 - 181 mg/100g) obtained by [28] for vegetables consumed in Pakistan [29]. The four vegetables analyzed are undeniable sources of calcium, thus their consumption would be important for the populations. Indeed, calcium is a major structural component of bones and teeth, and is essential for blood clotting, maintenance of blood pressure and acid-base balance in the blood, nerve regulation, muscle contraction, and cellular metabolism. In addition, it is involved in the reduction of colorectal adenomas and cholesterol [43].

3.3.4 Magnesium content

For *A. hybridus* leaves (Fig. 1), the magnesium contents indicate a significant difference between the sites. However, there was no significant difference between amaranth from the total market (1417.03 ± 3.26 mg/100g DW) and PK market (1538.26 ± 3.22 mg/100g DW). The magnesium content of amaranth from the municipal garden (2132.31 ± 3.25 mg/100g DW) was the highest and that from the Agri-C Mayanga site was 1748.37 ± 3.25 mg/100g DW. The contents obtained for amaranth in this study, were higher compared to those obtained by [25]

Table 3. Ca/P ratio in the four leafy vegetables collected

Vegetables	Municipal garden	Sites Total market	Agri C. Mayangua	PK market
A. <i>hybridus L</i>	4.59	0,90	4,08	1,24
B. <i>alba L</i>	4.20	1,99	0,71	1,95
I. <i>batatas L</i>	2.34	0,46	0,85	0,60
S. <i>nigrum L</i>	2.56	0,26	0,59	1,79

for *Amaranthus cruentus* (930 mg/100g) and *Amaranthus viridis* (540 mg/100g). However, they are lower than those reported by [12] for 16 genotypes of *Amaranthus blitum* (2863±18-3543±12 mg/100g). For *Basella alba* leaves (Fig. 2), the magnesium contents between sites were significantly different ($P < 0.05$). The Agri-C mayanga market garden site (2434.43 ± 3.26 mg/100g DW) and the PK market (2331.25 ± 3.26 mg/100g DW) had the highest levels of magnesium than the other two sites. The magnesium content of the total market (946.58 ± 3.15 mg/100g DW) was the lowest and that of the municipal garden was 1156.95 ± 3.05 mg/100g DW. These values were lower to that obtained by [33] for *B. alba* (2513.99 ± 11.00) consumed in Southern Côte d'Ivoire. In the case of *I. batatas* leaves (Fig. 3), the magnesium content at Agri C. Mayanga (1545.15 ± 2.25 mg/100g DW) was the highest and significantly different ($P < 0.05$) from that at the municipal garden (853.06 ± 2.23 mg/100g DM), total market (679.21 ± 2.25 mg/100g DW) and PK market (1043.85 ± 2.25 mg/100g DW) sites. Content magnesium from that at the municipal garden and total market ranged from 220.2 ± 2.4 to 910.5 ± 1.3 mg/100 g DW reported by [23]. However, those of Agri C. Mayanga and PK market are higher than the values obtained by [33]. For *S. nigrum* leaves (Fig. 4), the magnesium contents show a significant difference from one site to another. The magnesium content of vegetables collected at Agri C. mayanga was higher than those from the municipal garden, total and PK markets with values of 703.86 ± 0.21; 833.19 ± 0.25 and 1136.70 ± 0.23 mg/100g DW respectively. Furthermore, the values of *S. nigrum* L from Agri C. mayanga site and total market are higher than the magnesium content reported by [25] for *S. nigrum* (1080mg/100g) consumed in Nigeria. The values in the present study are higher compared to those reported by [28] for five wild vegetables (57.38 ± 1.16-315.21±1.24 mg/100g) consumed in Bangladesh. The four vegetables studied have magnesium contents above the recommended daily value for magnesium of 300 mg [44]. The indispensability of magnesium is linked to its

intervention with phosphate to stabilize nucleic acids. In addition, more than 300 enzymes require magnesium ions for their catalytic activities [45]. Magnesium is also involved in hundreds of biochemical reactions in the body. It reduces diseases such as hypertension, stroke, cardiometabolic syndrome and type 2 diabetes mellitus, airway constriction syndromes and asthma, depression, Alzheimer's disease and other psychiatric dementia syndromes, muscle diseases (muscle pain, chronic fatigue and fibromyalgia), bone fragility and cancer [46].

3.3.5. Ca/P ratio in the analyzed vegetables

The values of the Ca/P ratio in the analyzed vegetables from the different collection sites are presented in Table 3.

This table shows that the Ca/P ratio varied from 0.90 (total market) to 4.59 (municipal garden) for *A. hybridus*; 0.71 (Agri C. mayanga) to 4.20 (municipal garden) for *B. alba* L; 0.46 (total market) to 2.34 (municipal garden) for *I. batatas* and 0.26 (total market) to 2.56 (municipal garden) for *S. nigrum*. Ca/P ratio is used to evaluate food according to its potential to provide calcium and to increase or not its assimilation in the small intestine [47]. Food is classified as good if the Ca/P ratio is superior to 1 and as bad if it is inferior to 0.5 [48,37]. With regard to this standard, the vegetables analyzed, with the exception of *S. nigrum* and *I. batatas* leaves collected from the Total market, can all be considered relatively good food since their Ca/P ratio is between 0.59 and 4.59. This table also shows that the highest Ca/P ratio (above 2) were found on the market garden site of the municipal garden for all the vegetables analyzed. Thus, the vegetables collected at this site could be considered as the best.

4. CONCLUSION

The objective of the present work was to determine the composition in some macronutrients and micronutrients of four leafy vegetables, namely: *Amaranthus hybridus* L, *Basella alba* L, *Ipomea batatas* L et *Solanum*

nigrum. The results show that all the vegetables are rich in moisture, which limits their conservation for a long period. In addition, the vegetables studied were rich in protein, ash and minerals such as P, Ca, Mg and Fe. They contain very little lipids or fats and have a pH close to neutral. These results suggest that the consumption of sufficient quantities of these locally available and accessible vegetables contribute to the improvement of nutritional status and adequate protection against non-communicable diseases such as: cardiovascular disease, diabetes and obesity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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