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Evaluation of the Biochemical, Antioxidant and Organoleptic Properties of Three Combinations of Pairs of Leafy Vegetables from the Department of Korhogo (Ivory Coast)

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Abstract

In Côte d'Ivoire, leafy vegetables are grown, sold, and consumed. The objective of this study was to contribute to food security by promoting the nutritional potential of three pairs of leafy vegetables consumed by the Ivorian population: *Amaranthus hybridus* + *Ipomoea batatas* (A), *Amaranthus hybridus* + *Basella alba* (B), and *Ipomoea batatas* + *Basella alba* (C). The biochemical, antioxidant, and anti-nutritional parameters were analyzed using standard methods. Regarding biochemical properties, the moisture, ash, lipid, protein, fiber, and carbohydrate content of combinations A, B, and C varied from 3 ± 0 to 3.1 ± 0.1, 10.6% to 14.2%, 5.5% ± 0.1% to 6.8% ± 0.2%, from 27.68 ± 0.0 to 29.68 ± 1.47; from 39.25% ± 0.25% to 44.75% ± 0.25% and from 46.445% ± 0.00% to 50.82% ± 0.02%. The mineral content varies from 3094 ± 5.00 mg/100g to 5267 ± 2.00 mg/100g; from 498.4 ± 2.00 mg/100g to 841.8 ± 2.00 mg/100g; from 47.47 ± 0.2 mg/100g to 90.6 ± 2 mg/100g from 5.6 ± 2 to 15.04 ± 0.2 from 2203 ± 2 to 3181 ± 2 and from 727.9 ± 2 to 930 ± 2 respectively for calcium, magnesium, iron, zinc, potassium, and phosphorus, respectively. In terms of antioxidant properties, the polyphenol and flavonoid content and antioxidant activity vary from 363.5 ± 0.00 mg/100g DM to 378.5 ± 0.00 mg/100g DM, respectively; from 267 ± 0.014 mg/100g DM to 383 ± 0 mg/100g DM and from 80.35% ± 0.01% to 84.58% ± 0.00%. The oxalate and phytate content varied from 166.1 ± 0.25 mg/100g DM to 256.3 ± 0.15 mg/100g DM and from

4.7166 ± 0.00 mg/100g DM to 9.725 ± 0.00 mg/100g DM, respectively. The organoleptic evaluation revealed that combination B was generally acceptable, with the majority of panelists rating its color, aroma, and taste as "fairly to very pleasant." The results suggest that combination B could be preferred for optimal consumption due to its organoleptic qualities and balanced nutritional composition.

Keywords

Leafy Vegetables, Combination, Nutritional and Organoleptic Properties

1. Introduction

Diet plays a crucial role in human health. To this end, the careful selection of nutrient-rich foods such as leafy vegetables is essential. Due to their high micronutrient content, particularly minerals and provitamin A [1], leafy vegetables play an important role in the diets of many populations around the world, particularly in Africa and Asia. Their regular consumption contributes significantly to improving the nutritional quality of diets [2]. They are of paramount importance in agriculture and food because they provide significant income in both rural and urban areas [3]. They are sources of vitamins (A, B, and C), trace elements, protein, fiber, and carbohydrates [4]. They therefore contribute to improving the nutritional status of rural and urban populations. They are used in certain local recipes that reflect cultural identity or are considered national culinary specialties. Furthermore, they are available all year round, can be found in small local markets close to households, and are part of the dietary habits of the populations most affected by malnutrition. In Côte d'Ivoire, traditional leafy vegetables in particular are grown, sold, and consumed according to region. As a result, corète potagère is consumed in the center, while amaranth, Guinea sorrel, and black nightshade are consumed in the north. Celosia, okra leaves, and cassava leaves are popular in the west, and African spinach in the south [5]. In addition, there are more than 20 species of cultivated leaves in Côte d'Ivoire, many of which are consumed by the populations of the north [6]. These include *Hibiscus sabdariffa* (dah), *Amaranthus hybridus* (borombrou), *Adansonia digitata* (baobab), *Vigna unguiculata* (bean), *Ceiba pentandra* (cotton tree), *Celosia argentea* (sioko), *Basella alba* (spinach), and *Ipomoea batatas* (sweet potato). However, it should be noted that most plant-based foods undergo physical processing (husking, grinding, soaking, drying, cooking, refrigeration, etc.) or biochemical processing (fermentation, etc.) before consumption. These various technological processes prior to preparation can affect their nutritional and organoleptic value [7]. Several studies have shown that technological treatments, such as cooking, induce changes in the structure, texture, and nutritional value of foods [8] [9]. It is important to note that leafy vegetables are increasingly being combined in households for cooking. To date, several studies have been conducted on the biochemical and nutritional characteristics of uncombined leafy vegetables, but no study has been conducted on the nutritional and organoleptic characteristics of the combination of leafy vegetables consumed in Ivorian households. Given the importance of these leafy vegetables in the diet of the Ivorian population, particularly in northern Côte d'Ivoire, it would be wise to conduct this study to assess the nutritional and organoleptic quality provided by the combination of these commercial leafy vegetables, specifically the leaves of *Amaranthus hybridus* (bonnanbrou leaves), *Basella alba* (spinach leaves), and *Ipomoea batatas* (potato leaves), which are the focus of this study. The overall objective of this study is to contribute to food security by promoting the nutritional potential of the combination of three leafy vegetables (*Amaranthus hybridus*, *Basella alba*, and *Ipomoea batatas*) consumed by the Ivorian population.

2. Materials and Methods

2.1. Samples Collection

The biological material used in this study consisted of leaves from: *Ipomoea batatas* (sweet potato leaves), *Amaranthus hybridus* (bonnanbrou leaves), and *Basella alba* (spinach leaves). The leaves of *Ipomoea batatas*, *Amaranthus hybridus*, and *Basella alba* used in this study came from market gardens in Korhogo and were purchased fresh at small markets in the Cocody and Haoussabougou neighborhoods and at the large market in the city of Korhogo.

2.2. Pre-Treatment of Leafy Vegetables Combined in Pairs

Leafy vegetables are treated according to the method described by [10]. After purchase, the leaves of *Ipomoea batatas*, *Amaranthus hybridus*, and *Basella alba* are transported to the laboratory at Peleforo Gon Coulibaly University in Korhogo, where they are sorted (by species and undamaged leaves), separated from their stems, and washed with water. The leafy vegetables are weighed in batches of 875g for each sample before being combined in pairs to form threecombination batches, namely:

Batch A (1750 g): (*Ipomoea batatas* and *Amaranthus hybridus*).

Batch B (1750 g): (*Amaranthus hybridus* and *Basella alba*).

Batch C (1750 g): (*Ipomoea batatas* and *Basella alba*).

2.3. Water Cooking Treatment of Leafy Vegetables Combined in Pairs

The water cooking of the three combinations of leafy vegetables studied was carried out according to the method described by [11], with modifications. A mass of 1750 g of fresh combined leaves was immersed in a stainless-steel container containing 3 L of non-mineralized water. The water was brought to a boil (100˚C) and then the combinations of leafy vegetables were added when the water temperature reached 100˚C for 25 minutes, Recommended cooking maximum time after studies on the nutritional value of five leafy vegetables consumed in Ivory Coast.

After cooking, the cooked leaves are removed from the boiling water and left to drain at room temperature for a few minutes before being placed in the oven. The three batches of leafy vegetables are dried in the oven at 60˚C for 48 hours. After drying, the three batches of leafy vegetables are ground using a micro grinder and then sieved. The powders from the combinations are stored in sterile jars and used for analyses requiring dry matter.

2.4. Proximate Analysis

2.4.1. Moisture

Moisture content was determined using the [12] method. 5 grams weighed into a pre-weighed crucible and dried at 105˚C for 24 hours until a constant weight was achieved. After drying, the crucible was removed from the oven, cooled in a desiccator, and weighed. Moisture content was calculated using the formula:

$$\text{Moisture (\%)} = (m_1 - m_2) \times 100/m_e$$

where, m_1: Mass of the crucible + sample before drying; m_2: Mass of the crucible + sample after drying; m_e: mass of the dried powdered samples.

2.4.2. Ash

Ash content was determined using the method [12]. 5 g of dried powdered samples were weighed into a pre-weighed crucible and incinerated in a muffle furnace at 550˚C for 12 hours. After incineration, the crucible containing the ash was cooled in a desiccator and weighed. Ash content was calculated as follows: Ash (%) = $(m_1 - m_0) \times 100/m_e$. where, m_0: Mass of the crucible; m_1: Mass of the crucible + Ash; m_e: Mass of the dried powdered samples.

2.4.3. Lipids

Lipids content was determined using the Soxhlet extraction method [13]. 10 g of dried powdered samples were weighed into a cellulose extraction cartridge, sealed with cotton, and placed in the Soxhlet extractor with 300 mL of hexane. Extraction was carried out under reflux for seven hours. After extraction, the hexane was evaporated using a rotary evaporator, and the pre-weighed flask containing the oil was dried at 100˚C for 20 minutes, cooled in a desiccator, and weighed. Lipid content was calculated as follows Lipids (%) = $(m_1 - m_0) \times 100/m_e$ where, m_0: Mass of the empty flask; m_1: Mass of the flask + oil; m_e: Mass of the dried powdered sample.

2.4.4. Proteins

Proteins content was determined using the Kjeldahl method [12]. 1 g of dried powdered samples was digested in 20 mL of concentrated sulfuric acid at 400˚C for two hours with a mineralization catalyst (potassium sulfate + selenium). After digestion, the digest was diluted to 100 mL with distilled water. A 10 mL aliquot was mixed with 10 mL of 40% NaOH, and the mixture was distilled. Distillate was collected in 20 mL of 4% boric acid containing a mixed indicator (methyl red + bromocresol green) and titrated with 0.1 N sulfuric acid. Protein content was calculated as follows: Proteins (%) = ($V_1 - V_0$) × 14 × N × 6.25/m_e where, V_1: Volume of sulfuric acid for the sample; V_0: Volume of sulfuric acid for the blank; N: Normality of sulfuric acid; m_e: Mass of the sample.

2.4.5. Fibers

For crude fibers, [14] method was used. 2 g of dried powdered samples were weighed into separate 250 mL round-bottom flasks, and 50 mL of 0.25 M sulfuric acid solution was added. The mixture obtained was boiled under reflux for 30 min. Thereafter, 50 mL of 0.3 M sodium hydroxide solution was added and the mixture was boiled again under reflux for 30 min and filtered through Whatman paper. The insoluble residue was then incinerated, and weighed for the determination of crude fibers content. Fibers (%) = ($m_1 - m_2$) × 100/m_e.

2.4.6. Carbohydrates and Energy Value

Carbohydrates content and calorific value were calculated and expressed on a dry matter basis using the following formulas [15]: Carbohydrates (%) = 100 − [Moisture (%) + Lipids (%) + Proteins (%) + Ash (%) + Fiber (%)]; Energy (kcal/100g) = (% proteins × 2.44) + (% carbohydrates × 3.57) + (% lipids × 8.37).

2.4.7. Mineral Analysis

The dried powdered samples 5 g were burned to ashes in a muffle furnace (Pyrolabo, France). The ashes obtained were dissolved in 10 mL of HCL/HNO_3 and transferred into 100 mL flasks and the volume was made up using deionized water. The mineral composition of each sample was determined using an Agilent 7500c inductively coupled argon plasma mass spectrometer ICP-MS method [16]. Calibrations were performed using external standards prepared from a 1000 ppm single stock solution made up with 2% (v/v) nitric acid.

2.5. Anti-Nutritional Factors Determination

2.5.1. Oxalates

Oxalates content was performed using titration method by Day and [17]. One g of dried powdered sample was weighed into 100 mL conical flask. A quantity of 75 mL of sulphuric acid 3 M was added and stirred for 1 h with a magnetic stirrer. The mixture was filtered and 25 mL of the filtrate was titrated while hot against KMnO4 solution 0.05 M to the endpoint.

2.5.2. Phytates

Phytates contents were determined using Wade's reagent colorimetric method by [18]. A quantity 1 g of dried powdered sample was mixed with 20 mL of hydrochloric acid 0.65 N and stirred for 12 h with a magnetic stirrer. The mixture was centrifuged at 12,000 rpm for 40 min. An aliquot 0.5 mL of supernatant was added with 3 mL of Wade's reagent. The reaction mixture was incubated for 15 min and absorbance was measured at 490 nm using a spectrophotometer (PG Instruments, England). Phytate content was estimated using a calibration curve of sodium phytate 10 mg/mL as standard.

2.6. Determination of Antioxidant Properties

Extraction of Phenolic Compound

Phenolic compounds are extracted with methanol using the method described by [19]. 1 gram of the combination of oven-dried and crushed leaves is homogenized in 10 mL of 70% (v/v) methanol. The resulting mixture is centrifuged at 1000 rpm for 10 min. The pellet is recovered in 10 mL of 70% methanol (v/v) and centrifuged again. The supernatants are combined in a 50 mL flask and adjusted with distilled water to the mark. The solution thus obtained is called the methanol extract.

1) Polyphenol content

Add 1 mL of Folin-Ciocalteu reagent to 1 mL of methanolic extract, then add 1 mL of 20% (w/v) sodium carbonate solution. Fill the tube to 10 mL with distilled water and place it in the dark for 30 min. The optical density is read at 725 nm against a blank. A standard curve established from a stock solution of gallic acid (1 mg/mL) under the same conditions as the test is used to determine the amount of phenols in the sample.

2) Flavonoid content

The method used to determine flavonoid content is that described by [20]. To 0.5 mL of methanolic extract, 0.5 mL of distilled water, 0.5 mL of aluminum chloride, 0.5 mL of potassium acetate, and 2 mL of distilled water are added successively. The tube is left to stand for 30 min in the dark and the optical density (OD) is read at 415 nm against a blank. A calibration curve prepared under the same conditions as the test using a 0.1 mg/mL quercetin stock solution is used to determine the flavonoid content of the samples.

3) Measurement of antioxidant activity using the DPPH method

Antioxidant activity is determined according to the method described by [21]. About 1 mL of 0.3 mM DPPH solution in ethanol was added to 2.5 mL of sample solution 1 g of dried powdered sample mixed in 10 mL of methanol, filtered through Whatman No. 4 filter paper, and allowed to react for 30 min at room temperature. Absorbance values were measured with a spectrophotometer (PG Instruments, England) set at 415 nm. The average absorbance values were converted to percentage antioxidant activity using the following formula: Antioxidant activity (%) = 100 − [(Abs of sample − Abs of blank) × 100/Abs positive control].

2.7. Analysis of Organoleptic Properties

The sensory analysis of the leafy vegetable combinations studied was carried out according to the method described by [22], which consisted of conducting an acceptability test with a panel of fifteen (15) tasters. The panelists were asked to evaluate the three combinations based on quality attributes such as color, texture, aroma (smell), and overall acceptability. A five-point hedonic scale was used, ranging from very pleasant to very unpleasant.

2.8. Statistical Analyses

All tests were performed in triplicate and the results are expressed as mean ±

standard deviation. Analysis of variance (ANOVA) was performed using SPSS Statistics 22 software. Tukey's test at a 5% threshold was used to determine significant differences between means.

3. Result and Discussion

3.1. Proximate Composition

Table 1 presents the physicochemical and biochemical properties of the combined leafy vegetables. Analysis of the data indicates that there is a significant difference between the values obtained for all the properties studied for combinations A, B, and C at a 5% risk level. The moisture content is 3.1% ± 0.1% for all combinations A, B, and C, respectively. According to [23], the low moisture content observed in leaf combinations A, B, and C could indicate an increase in nutrient concentration. The ash content of the combinations varies from 10.6% to 14.2% for combinations A, B, and C, respectively. Combination B has the highest ash content compared to combinations A and C. The results of this study are higher than those obtained by [9], who obtained 8.26 ± 0.34% in studies involving sun drying of uncombined leafy vegetables for two days. The ash content obtained in the different combinations of leafy vegetables studied indicates a significant presence of minerals in these combinations of leafy vegetables. The lipid content values ranged from 5.5% ± 0.1% to 6.8% ± 0.2% for combinations A, B, and C, respectively. The highest lipid content was obtained with combination C and the lowest with combination A. The low lipid content of the combinations studied, consistent with the observations of other authors, could be due to cell rupture and the release of lipids into the cooking water [24] [25]. Thus, these combinations of leafy vegetables would be suitable for people seeking to limit their lipid intake. These combinations of leafy vegetables could be recommended for people who are obese or following a low-fat diet. In terms of crude protein content, the values obtained range from 27.68 ± 0.0 to 29.68 ± 1.47 for combinations A, B, and C, respectively. The results of this study are higher than those reported [26] on uncombined leafy vegetables after 25 minutes of boiling. Combinations A, B, and C showed good values after cooking. These combinations could be considered significant sources of protein given their content (27.68%, 28.68%, and 29.68%), which is higher than the minimum value (12%) recommended for protein-rich foods [27]. To this end, combinations of leafy vegetables A, B, and C cooked for 25 minutes could be recommended in the diets of populations that have little meat or fish available, as well as for pregnant or breastfeeding women. The dietary fiber content of the leafy vegetable combinations studied is also interesting. For example, the combination of leafy vegetables A, B, and C with high fiber content (44.75%, 44.5%, and 39.25%) could be used to reduce the risk of constipation, diabetes, irritable bowel syndrome, and breast cancer [28]. Cooking tends to increase soluble fiber, which is beneficial for intestinal transit and reducing cholesterol and glucose absorption [29]. As for carbohydrate content, the values observed ranged from 46.44% ± 0.0% to 50.82% ± 0.02% for combinations A, B, and C, respectively. Combination A had the highest content compared to combinations B and C. The leafy vegetable combinations studied could be good sources of carbohydrates and could therefore be used as a supplement in the preparation of infant foods. The energy values of the combinations of leafy vegetables studied (295.00 ± 0.00; 288.31 ± 0.01 and 303.37 ± 0.00 kcal/100g) are similar to the values reported for certain Nigerian vegetables (248.8 to 307.1 kcal/100g) [30]. Thus, the caloric values of the leafy vegetable combinations studied corroborate the general observation that leafy vegetables have low energy values due to their low crude fat content and relatively high moisture content [31]. This justifies the consumption of leafy vegetables with carbohydrate-rich foods.

Table 1. Physicochemical and biochemical composition of leafy vegetable combinations A, B, and C.

	Samples		
	A (*A. hybridus* + *I. batatas*)	B (*A. hybridus* + *B. alba*)	C (*I.batatas* + *B. alba*)
Moisture %	3.1 ± 0.1a	3.1 ± 0.1^{a}	3.1 ± 0.1^{a}
Ash%	12.9 ± 0.1^{b}	14.2 ± 0.00^{a}	10.6 ± 0.00^{c}
Lipids %	5.5 ± 0.1^{b}	5.6 ± 0.00^{b}	6.8 ± 0.2^{a}
Proteins %	27.68 ± 0.01^{a}	28.68 ± 0.04^{a}	29.68 ± 1.47^{a}
Fibres %	44.75 ± 0.25^{a}	44.5 ± 1.00^{a}	39.25 ± 0.25^{b}
Carbohydrates %	50.82 ± 0.02^{a}	46.97 ± 0.00^{b}	$46/46 \pm 0.00^{c}$
Calorific value Kcal/100g	295.00 ± 0.00^{b}	288.31 ± 0.01^{c}	303.39 ± 0.00^{a}

Averages with the same superscript letter in the same row are not significantly different at the 5% level. A: *Amaranthus hybridus* and *Ipomoea batatas*; B: (*Amaranthus hybridus* and *Basella alba*); C: (*Ipomoea batatas* and *Basella alba*).

3.2. Mineral Composition

Mineral content is an essential component of the nutritive value of green leafy vegetable. Table 2 shows the mineral composition of the leafy vegetable combinations paired together. The mineral content of combinations A, B, and C are rich in calcium (3094 ± 5.00 to 5267 ± 2.00 mg/100mg), iron (47.47 ± 0.2 to 90.6 ± 2 mg/100mg), zinc (5.6 ± 2 to 15.04 ± 0.2 mg/100mg), potassium (2203 ± 2.00 to 3181 ± 2.00 mg/100mg), phosphorus (727.9 ± 2.00 to 930 ± 2.00 mg/100mg) and magnesium (498.4 ± 2.00 to 764.6 ± 2.00 mg/100mg). The mineral profile of foods is important because micronutrient deficiency, also known as "hidden hunger," is a major problem in developing countries. The mineral profile of foods is important because micronutrient deficiency, also known as "hidden hunger," is a major problem in developing countries. Given the recommended nutritional intake (RNI) for minerals, consumption of leafy vegetables combined in pairs could cover more than 50% of the RNI [32]. This pairing of leafy vegetables could therefore contribute significantly to improving human nutrition and reducing malnutrition linked to micronutrient deficiencies. It is important to note that calcium and phosphorus are associated with the growth and maintenance of bones, teeth, and muscles, while potassium may play a role in lowering blood pressure [33] [34]. High potassium content in the diet can protect people who are sensitive to high sodium levels from hypertension. As for magnesium, this mineral is known to prevent cardiomyopathy, muscle degeneration, growth retardation, birth defects, and bleeding disorders [35]. Iron is important in the diets of pregnant women, infants, and the elderly to reduce cases of deficiency associated with diseases such as anemia, while zinc is important for the metabolism of vitamins A and E [32].

Table 2. Mineral composition of leafy vegetable combinations A, B, and C in mg/100g.

	Samples		
	A (*A. hybridus* + *I. batatas*)	**B (*A. hybridus* + *B. alba*)**	**C (*I. batatas* + *B. alba***
Na	148.2 ± 2^{c}	164.1 ± 2^{b}	198.1 ± 2^{a}
Mg	764.6 ± 2^{b}	841.8 ± 2^{a}	498.4 ± 2^{c}
K	2426 ± 2^{b}	3181 ± 2^{a}	2203 ± 2^{c}
P	930 ± 2^{a}	921.7 ± 2^{a}	727.9 ± 2^{b}
Ca	5267 ± 2^{a}	5062 ± 2^{b}	3094 ± 5^{c}
Fe	90.6 ± 2^{a}	74.73 ± 0.2^{b}	47.47 ± 0.2^{c}
Zn	12.09 ± 0.4^{b}	15.04 ± 0.2^{a}	5.6 ± 2^{c}

Averages with the same superscript letter in the same row are not significantly different at the 5% level. A: (*Amaranthus hybridus* and *Ipomoea batatas*); B: (*Amaranthus hybridus* and *Basella alba*); C: (*Ipomoea batatas* and *Basella alba*).

3.3. Determination of the Anti-Nutritional Properties of Combined Leafy Vegetables

In order to predict the bioavailability of calcium (Ca) and iron (Fe), the ratios between antinutrients and nutrients were calculated (**Table 3**). The oxalate and phytate content of the leafy vegetable combinations studied is shown in **Figure 1**. The oxalate variations observed are 256.3 ± 0.15 mg/100g DM; 201.3 ± 0.65 mg/100g DM and 166.1 ± 0.25 mg/kg DM for combinations A, B, and C, respectively. Thus, combination C had the lowest value and combination A had the highest value. The variations in phytates observed are 8.63 ± 0.01 mg/100g DM; 4.72 ± 0.00 mg/100g DM and 9.73 ± 0.00 mg/100g DM for combinations A, B, and C, respectively. oxalates and phytates are anti-nutritional compounds that chelate divalent cations such as calcium, magnesium, zinc, and iron, reducing their bioavailability [36]. Taking into account the phytate/calcium and phytate/iron ratios, which are below the critical levels of 0.5 and 0.4 [37] in all combinations of leafy vegetables studied, the amounts of phytates after 25 minutes of cooking would not affect the bioavailability of calcium and iron for the body. The same applies to oxalates, whose content would not affect the bioavailability of calcium in combinations A, B, and C, given that the oxalate/Ca ratio is below the guideline value of 2.5 [37]. Cooking reduces anti-nutritional factors such as oxalates and phytates, thereby improving the bioavailability of minerals [38].

Table 3. Anti-nutritional factor/mineral ratios of leafy vegetable pair combinations.

	phytates/Ca	phytates/Fe	Oxalates/Ca
A (*A. hybridus* + *I. batatas*)	0.001	0.095	0.048
B (*A. hybridus* + *B. alba*)	0.001	0.063	0.039
C (*I. batatas* + *B. alba*)	0.003	0.020	0.053

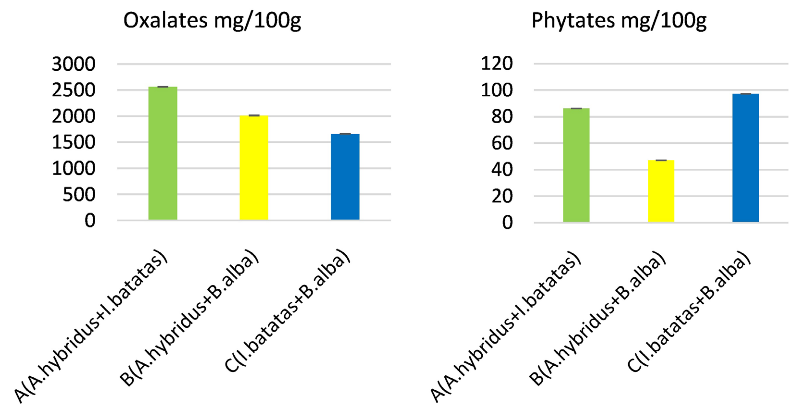


Figure 1. Oxalate and phytate content of combinations A, B and C.

3.4. Determination of the Antioxidant Properties of Leafy Vegetables Combined in Pairs

The results shown in **Figures 2-4** indicate that the concentration of polyphenols, flavonoids, and antioxidant activity varied depending on the type of combination. These variations ranged from 363.5 ± 0.00 mg/100g to 378.5 ± 0.00 mg/100g of DM; from 268 mg/100g to 383 mg/100g DM; from 80.35% ± 0.01% to 84.58% ± 0.00% respectively in polyphenols; flavonoids and antioxidant activity for combinations A, B, and C. Combination A, composed of *A. hybridus* and *I. batatas* leaves, had the highest polyphenol, flavonoid, and antioxidant activity content compared to combinations B and C. of *A. hybridus* and *I. batatas* leaves, had the highest polyphenol, flavonoid, and antioxidant activity content followed by the combinations B and C. The content of phenolic compounds, flavonoids, and antioxidant activity after 25 minutes of cooking in combined leafy vegetables is higher than that obtained by [26] after 25 minutes of boiling in water of non-combined leaves of *Hibiscus sabdariffa*, *Amaranthus Hybridus*, *Adansonia digitata*, *Vigna unguiculata*, and *Ceiba pentandra*. These high polyphenol, flavonoid, and antioxidant activity levels could be justified by the observations of other studies, suggesting that heat treatment promotes the release of antioxidants [39]. The benefit of polyphenols lies in their antioxidant properties, as they are capable of trapping free radicals that are constantly generated by our bodies or formed in response to environmental aggressions [40]. Flavonoids, meanwhile, have antioxidant activity that can combat oxidative stress, which is involved in the pathogenesis of various neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis [41]. The increase in antioxidant activity after cooking is therefore attributed to the increase in phenolic compounds in leafy vegetable combinations. Leafy vegetable combination A, consisting of *A. hybridus* and *I. batatas* leaves, could therefore be recommended for regular consumption.

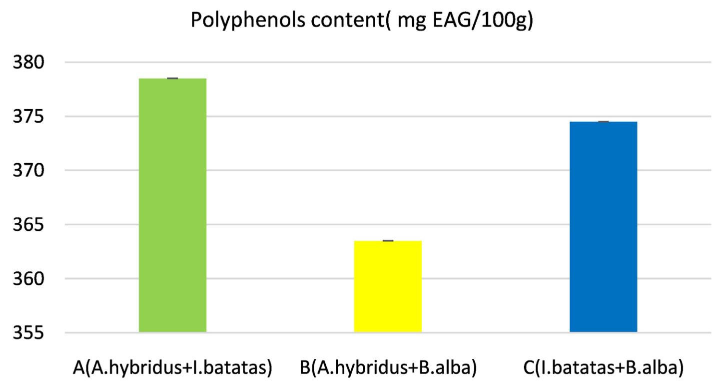


Figure 2. Polyphenol content of combinations A, B and C.

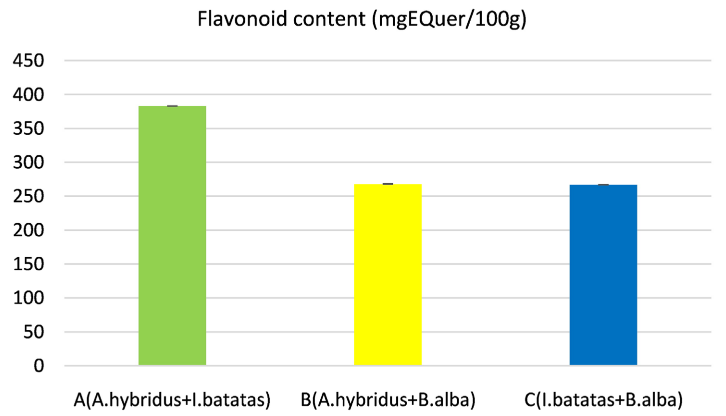


Figure 3. Flavonoid content of combinations A, B and C.

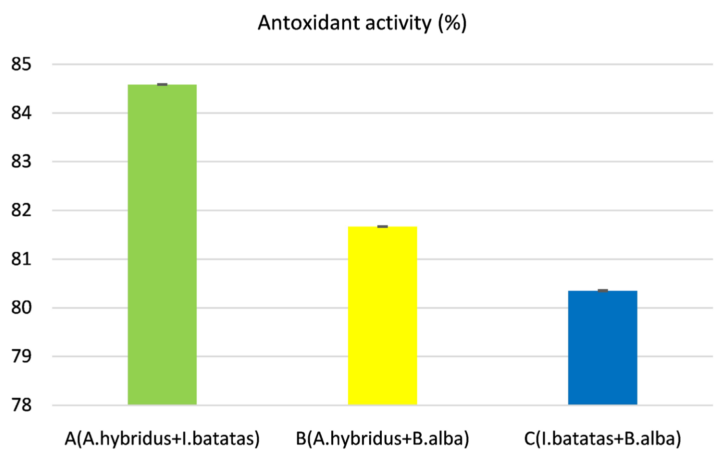
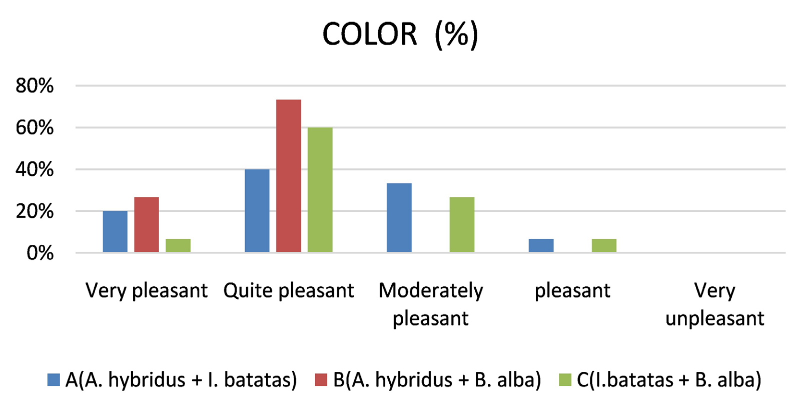


Figure 4. Antioxidant content of combinations A, B and C.

3.5. Analysis of Organoleptic Properties

The organoleptic analysis of leafy vegetable combinations carried out according to the method described by led to the development of Figure 5. The results showed the appreciation of the color, taste, aroma, and overall acceptability of the combinations by pairs of leafy vegetables A, B, and C. In terms of color, combination A was rated as very pleasant by 20%, fairly pleasant by 40%, pleasant by 6.67%, and moderately pleasant by 33.33%. Combination B was rated as very pleasant by 26.67% and fairly pleasant by 73.33%, with no panelists rating it as moderately pleasant, pleasant, or very unpleasant. Combination B received ratings of very pleasant (26.67%) and fairly pleasant (73.33%), with no panelists rating it as moderately pleasant, pleasant, or very unpleasant. Combination C was rated as "very pleasant" by 6.67% and "pleasant" by 26.67%, while 60% of panelists rated it as "fairly pleasant." In terms of aroma, combination A was rated as fairly pleasant by 40%, very pleasant by 26.67%, pleasant by 20%, and moderately pleasant by 13.33%. As for combination B, 20% of panelists rated it as very pleasant and pleasant, 46.67% rated it as fairly pleasant, and 13.33% rated it as moderately pleasant. Combination C received 20% for fairly pleasant and very unpleasant, then 40%, 13.33%, and 6.67% respectively for moderately pleasant, very pleasant, and pleasant. In terms of taste, 6.67% of panelists rated combination A as pleasant and very unpleasant, while 40%, 33.33%, and 13.33% rated it as fairly pleasant, moderately pleasant, and very pleasant, respectively. As for combination B, 20% of panelists rated it as pleasant and moderately pleasant, while 26.67% and 3.33% rated it as fairly pleasant and very pleasant, respectively. For combination C, 13.33% of panelists rated it as very pleasant, pleasant, and very unpleasant, while 33.33% and 26.67% rated it as fairly pleasant and moderately pleasant, respectively. Regarding overall acceptability, panelists rated combination A as very pleasant and pleasant at 20%, moderately pleasant at 33.33%, and fairly pleasant at 26.67%. As for combination B, the panelists rated it as very pleasant (26.67%), fairly pleasant (46.67%), moderately pleasant (20%), and very unpleasant (6.66%), while for combination C, 13.33% of the panelists rated it as fairly pleasant, pleasant, and very unpleasant. The ratings "very pleasant" and "moderately pleasant" were given by 20% and 40% of panelists, respectively.



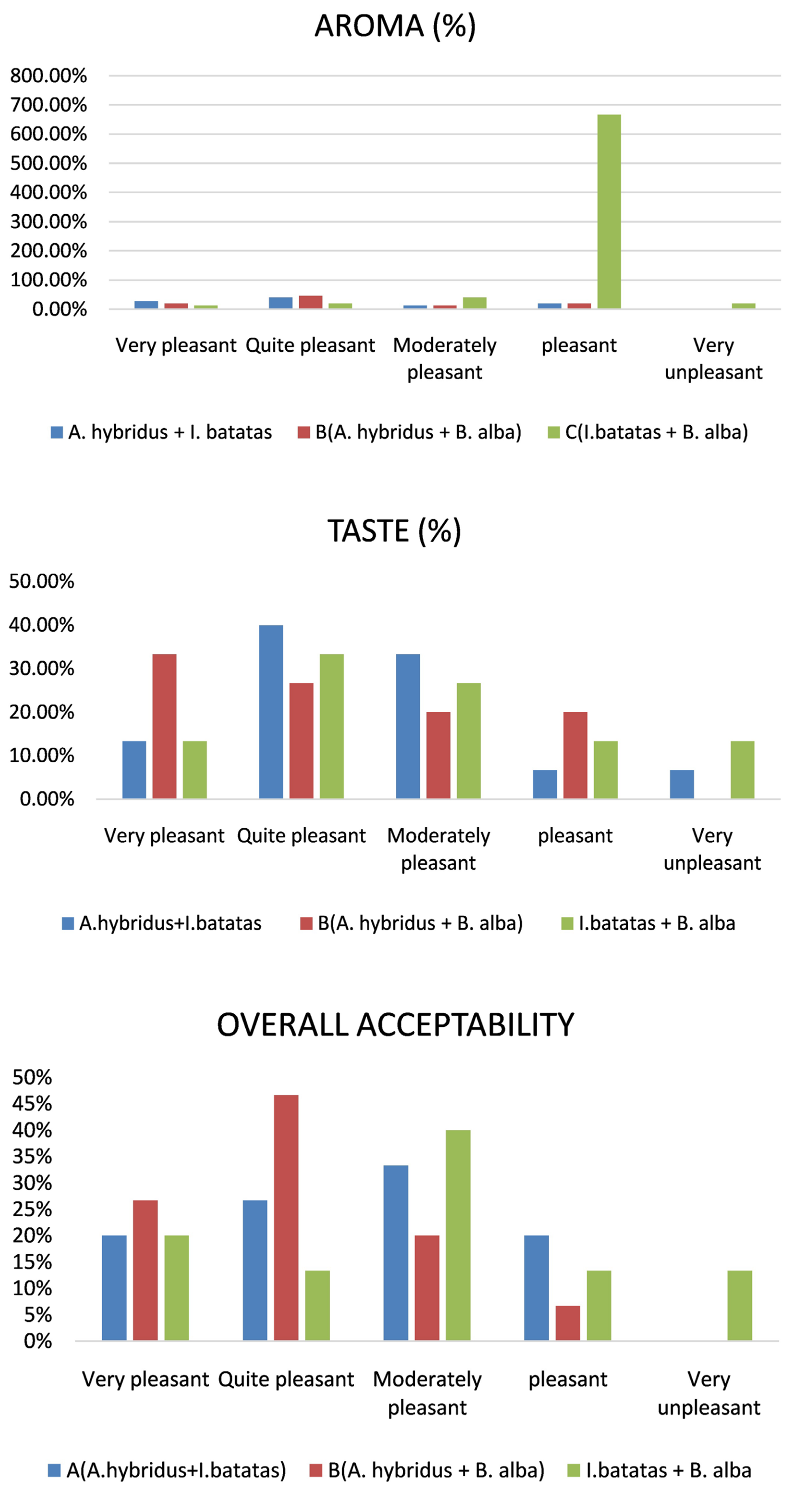


Figure 5. Assessment of the color, aroma, taste, and overall acceptability of combinations A, B, and C.

4. Conclusion

The aim of this study was to promote the combination of three leafy vegetables commonly consumed in northern Côte d'Ivoire (*Ipomoea batatas*, *Amaranthus hybridus*, and *Basella alba*) by evaluating their nutritional and organoleptic properties. The results obtained highlight an interesting nutritional composition, characterized by high levels of protein, fiber, carbohydrates, and minerals (Ca, Fe, Na, K, and Mg). In addition, high antioxidant activity was observed with combination A (*Amaranthus hybridus* and *Ipomoea batatas*), followed by combination B (*Amaranthus hybridus* and *Basella alba*), reinforcing the beneficial potential of these leafy vegetable combinations in the prevention of diseases related to oxidative stress. Despite the presence of certain antinutritional factors (oxalates, phytates) in the leafy vegetable combinations, their levels remain harmless to consumer health. Organoleptic analysis reveals good acceptability of the different combinations, particularly combination B, which combines *Amaranthus hybridus* and *Basella alba*, deemed more pleasant by tasters. Thus, combining leafy vegetables in pairs appears to be an effective strategy for improving the nutritional balance of diets while meeting the cultural and taste requirements of local populations. This approach contributes to the promotion of a healthy, diverse, and sustainable diet and is fully in line with efforts to strengthen food security in Côte d'Ivoire. The combination of leafy vegetables could then be recommended to the population in order to combat nutritional deficiencies and improve the quality of food, while promoting local resources that are often underutilized.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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