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STUDY OF ROASTING EFFECT ON NUTRITIVE AND ANTIOXIDANT PROPERTIES OF LEAFY VEGETABLES CONSUMED IN NORTHERN CÔTE D'IVOIRE

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Abstract: *African leafy vegetables (ALVs), also known as African spinach, contribute significantly to household food security and add variety to cereal-based staple diets. Five leafy vegetable species (Amaranthus hybridus, Andasonia digitata, Ceiba patendra, Hibiscus sabdariffa and Vigna unguiculata) that are used for sauce preparation in Northern Côte d'Ivoire were subjected to roasting in order to evaluate the impact of this non conventional processing method on their nutritive value and antioxidant properties. This study showed that longer time (higher than 2 min) of roasting at 180-200°C caused negative impact with nutrients losses but positive impact by reducing anti-nutrients such as oxalates and phytates. The registered losses at 2 min were as follow: ash (0.09 – 6.58 %), proteins (1.22 – 29.31 %), vitamin C (77.56 – 89.01 %), carotenoids (11.24 – 45.16%) oxalates (2.30 – 20.51 %) and phytates (5.20 – 63.82 %). Roasting processing of the studied leafy vegetables highlighted a significant increase (4.77 – 32.71 %) of polyphenols contents coupled with increasing of antioxidant activity. Moreover, after 2 min of roasting time, the residual contents of minerals were: calcium (294.78 - 879.74 mg/100g), magnesium (175.87 - 480.54 mg/100g), potassium (159.72 - 371.33 mg/100g), iron (15.54 - 84.97 mg/100g) and zinc (13.27 - 38.85 mg/100g). All these results suggest that roasting of leafy vegetables (less than 2 min) may be used as alternative method of cooking in order to minimize nutrients losses and to contribute efficiently to the food security of Ivorian population.*

Keywords: *antioxidant properties - roasting processing - leafy vegetables - nutritive value*

1. Introduction

Leafy vegetables are plants which leafy parts (young stems, flowers and young fruits) are used as vegetables. These plants have a unique place among vegetables because they are rich sources of many nutrients and antioxidant compounds [1,2]. Socio-economic surveys conducted in various parts of Africa indicate that ALVs are important commodities in household food and nutrition security [3].

Indeed, African leafy vegetables (ALVs) are the cheapest and most readily available sources of micronutrients and they provide also important sources of employment in peri - urban areas because of their short labour-intensive production system [4,5]. Leafy vegetables are obtained by harvesting or cultivation and their high moisture render them perishable and seasonal availability limits their utilization all round the year.

Hence, there is a need to preserve this nature's store house of nutrients through proper processing techniques for safe storage with efficient nutrient retention [6]. To extend the period during which they are available, different ways of preserving these vegetables have been developed. The two main methods are the sun-drying of fresh leaves and the sun-drying of blanched or cooked leaves. Both of these methods transform the leafy vegetables into dry products that have long shelf lives [7]. Electrification of the rural areas has introduced new preservation technology, including the freezing of leafy vegetables [8]. Among the twenty hundred and seven (207) leafy vegetables widely consumed in tropical Africa, about twenty (20) species of leafy vegetables belong to 6 botanical families, are widely consumed and cultivated by Ivorian population [9,10]. Furthermore, the consumption of these leafy vegetables is linked to the region and ethno-botanical studies have stated that most people in Northern Côte d'Ivoire consume indigenous green leafy vegetables such as *Amaranthus hybridus* "boronbrou", *Andasonia digitata* "baobab", *Ceiba patendra* "fromager", *Hibiscus sabdariffa* "dah" and *Vigna unguiculata* "haricot" [10,11]. Earlier reports have highlighted the nutritive potential of these fresh leafy vegetables [12]. For these species, the tender leaves are prepared as potherbs or as relishes, primarily to accompany starchy paste foods as cassava, maize and sorghum. These leafy vegetables may be prepared from a single species or from a combination of them. For cooking, the mature and freshly leaves are boiled in water for about 30 min in order to reduce bitter taste and then used, after discarding boiled water, for sauce preparation. In a lesser extent, blanching is also used to inactivate oxidative enzymes, destroy vegetative microbial cells, reduce or eliminate the bitterness and to remove any residual pesticides [13,14]. Even if some adverse effects such as nutrient losses have been reported [15,16] by using boiling or blanching processing, there is any scientific data with regards to the effect of roasting (oven-cooking) processing on the physicochemical and nutritive characteristics of leafy vegetables consumed in Northern Côte d'Ivoire. Therefore, the aim of this study is to evaluate the effect of roasting on the nutritive value of these selected leafy vegetables in order to provide necessary information for their wider utilization and contribution to food security of Ivorian population.

2. Material and methods

2.1. Samples collection

Leafy vegetables (*Amaranthus hybridus*, *Andasonia digitata*, *Ceiba patendra*, *Hibiscus sabdariffa* and *Vigna unguiculata*) were collected fresh and at maturity from cultivated farmlands located at Dabou (latitude: 5°19′14″ North; longitude: 4°22′59″West) (Abidjan District). The samples were harvested at the early stage (between one and two weeks of the appearance of the leaves). These plants were previously authenticated by the National Floristic Center (University Felix Houphouët-Boigny, Abidjan-Côte d'Ivoire).

2.2. Samples processing

The fresh leafy vegetables were rinsed with deionized water and the edible portions were separated from the inedible portion. The edible portions were chopped into small pieces (500 g) and allowed to drain at ambient temperature. Each sample was divided into two lots. The first lot (raw, 250 g) was dried in an oven (Memmert, Germany) [17], ground with a laboratory crusher (Culatti, France) equipped with a 10 µm mesh sieve. The powdered samples were stored in a clean dry air-tight sample bottle in a refrigerator (4°C) until further analyses. The second lot (250 g) was roasted (oven-cooking) for 2, 4 and 6 min at 180-200°C. The roasted samples were cooled at ambient temperature and subjected to the same treatment using for raw samples.

2.3. Chemicals

All solvents (n-hexane, petroleum ether, acetone, ethanol and methanol) were purchased from Merck. Standards used (gallic acid, β-carotene) and reagents (metaphosphoric acid, Folin-Ciocalteu, DPPH) were purchased from Sigma-Aldrich. All chemicals used in the study were of analytical grade.

2.4. Nutritive properties

2.4.1. Proximate analysis

Proximate analysis was performed using official methods [18]. The moisture content was determined by the difference of weight before and after drying the sample (10 g) in an oven (Memmert, Germany) at 105°C until constant weight. Ash fraction was determined by the incineration of dried sample (5 g) in a muffle furnace (Pyrolabo, France) at 550°C for 12 h. The percentage residue weight was expressed as ash content. For crude fibres, 2 g of sample were weighed into separate 500 mL round bottom flasks and 100 mL of 0.25 M sulphuric acid solution was added. The mixture obtained was boiled under reflux for 30 min. Thereafter, 100 mL of 0.3 M sodium hydroxide solution was added and the mixture were 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 fibres content. Proteins were determined through the Kjeldhal method and the lipid content was determined by Soxhlet extraction using hexane as solvent. Carbohydrates and calorific value were calculated using the following formulas [19]:

Carbohydrates: 100 – (% moisture + % proteins + % lipids + % ash + % fibres).

Calorific value: (% proteins x 2.44) + (% carbohydrates x 3.57) + (% lipids x 8.37).

The results of ash, fibres, proteins, lipids and carbohydrates contents were expressed on dry matter basis.

2.4.2. Mineral analysis

Minerals contents were determined by the ICP-MS (inductively coupled argon plasma mass spectrometer) method [20]. 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 argon plasma mass spectrometer. Calibrations were performed using external standards prepared from a 1000 ppm single stock solution made up with 2% nitric acid.

2.4.3. Anti-nutritional factors

Oxalates content was performed using a titration method [21]. One (1) 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 $KMnO_4$ solution (0.05 M) to the end point. Phytates contents were determined using the Wade's reagent colorimetric method [22]. 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. The mixture was centrifuged at 12000 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 by using a spectrophotometer (PG Instruments, England). Phytates content was estimated using a calibration curve of sodium phytate (10 mg/mL) as standard/

2.5. Antioxidant properties

2.5.1 Vitamin C and carotenoids determination

Vitamin C contained in analyzed samples was determined by titration [23]. About 10 g of ground fresh leaves were soaked for 10 min in 40 mL metaphosphoric acid-acetic acid (2%, w/v). The mixture was centrifuged at 3000 rpm for 20 min and the supernatant obtained was diluted and adjusted with 50 mL of bi-distilled water. Ten (10) mL of this mixture was titrated to the end point with dichlorophenol-indophenol (DCPIP) 0.5 g/L. Carotenoids were extracted and quantified by using a spectrophotometric method [24].

Two (2) g of ground fresh leaves were mixed three times with 50 mL of acetone until loss of pigmentation. The mixture obtained was filtered and total carotenoids were extracted with 100 mL of petroleum ether. Absorbance of extracted fraction was then read at 450 nm by using a spectrophotometer (PG Instruments, England). Total carotenoids content was subsequently estimated using a calibration curve of β-carotene (1 mg/mL) as standard.

2.5.2. Polyphenols determination

Polyphenols were extracted and determined using Folin–Ciocalteu's reagent [25]. A quantity (1 g) of dried powdered sample was soaked in 10 mL of methanol 70% (w/v) and centrifuged at 1000 rpm for 10 min. An aliquot (1 mL) of supernatant was oxidized with 1 mL of Folin–Ciocalteu's reagent and neutralized by 1 mL of 20% (w/v) sodium carbonate. The reaction mixture was incubated for 30 min at ambient temperature and absorbance was measured at 745 nm by using a spectrophotometer (PG Instruments, England). The polyphenols content was obtained using a calibration curve of gallic acid (1 mg/mL) as standard.

Antioxidant activity

Antioxidant activity assay was carried out using the 2,2-diphenyl-1-pycrilhydrazyl (DPPH) spectrophotometric method [26]. 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 and filtered through Whatman No. 4 filter paper) and was 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) x 100/Abs positive control]

Statistical analysis

All the analyses were performed in triplicate and data were analyzed using EXCELL and STATISTICA 7.1 (StatSoft). Differences between means were evaluated by Duncan's test. Statistical significant difference was stated at $p < 0.05$

3. Results and discussion

The proximate composition of the roasted leafy vegetables is presented in Table 1. The physicochemical parameters generally differ significantly ($p<0.05$) from a roasting time of a leafy vegetable to another. The ash content after 2 min of roasting ranged from 8.19 ± 0.00% (*A. hybridus*) to 23.90 ± 0.24% (*C. patendra*). These values were closed to 7.66 ± 0.18%

and 21.69 ± 1.56% after 6 min of roasting. The observed decrease rate at 2 min of roasting ranged from 0.09 to 6.58 % in the following order: *V. unguiculata* (0.09%) > *A. digitata* (1.55%) > *A. hybridus* (4.65%) > *H. sabdariffa* (5.43%) > *C. patendra* (6.58%). These losses are lower than that (9.78 – 28%) reported for boiled Nigerian leafy vegetables [27].

Therefore, roasting processing could be advantageous for mineral quality preservation of leafy vegetables. As concern protein contents, roasting processing caused 1.22 to 29.31% reduction after 2 min. These proteins losses increased in the order: *V. unguiculata* (1.22%) > *A. hybridus* (3.16%) > *H. sabdariffa* (10.29%) > *C. patendra* (12.56%) > *A. digitata* (29.31%).

This reduced protein contents could be attributed to the severity of thermal process (180-200°C) which leads to protein degradation [28].

However, this thermal processing could enhance the digestibility of proteins by degradation of anti-nutritional factors such as tannins [29]. With regards to their protein contents (12.78 – 21.69%) at 2 min, roasted leaves of the selected species could be considered as non negligible sources of proteins for human nutrition. Roasting of the studied leafy vegetables resulted in a slight increase ($p > 0.05$) in their crude fibres content (0.9 – 4.27%) after 2 min of heat application.

Table 1.

Proximate composition of raw and roasted leafy vegetables consumed in Northern Côte d'Ivoire

	Ash (%)	Fibres (%)	Proteins (%)	Lipids (%)	Carbohydrates (%)	Calorific value (kcal /100g)
H. sabdariffa						
Raw	10.30 ± 0.10a	14.27 ± 1.70b	14.47 ± 0.10a	4.75 ± 0.15a	56.21 ± 1.78b	275.71 ± 0.55a
2 min	9.74 ± 0.09b	14.40 ± 1.99b	12.98 ± 0.01b	4.87 ± 0.01a	59.73 ± 6.88a	271.28 ± 4.68a
4 min	9.60 ± 0.23b	14.67 ± 1.56b	12.36 ± 0.00b	4.92 ± 0.03a	59.11 ± 4.30a	276.85 ± 5.60a
6 min	9.26 ± 0.64b	16.00 ± 1.24a	12.15 ± 0.00b	4.95 ± 0.01a	54.64 ± 2.41b	266.13 ± 8.49b
A. hybridus						
Raw	8.59 ± 1.34a	17.80 ± 0.30a	13.25 ± 0.13a	2.15 ± 0.01b	58.21 ± 1.78a	305.19 ± 7.73a
2 min	8.19 ± 0.00a	17.19 ± 2.21a	12.83 ± 0.04b	2.48 ± 0.03b	60.21 ± 2.26a	259.46 ± 7.85c
4 min	8.03 ± 1.43a	17.28 ± 1.24a	12.24 ± 0.00b	2.54 ± 0.06b	59.91 ± 3.87a	265.02 ± 3.34c
6 min	7.66 ± 0.18b	17.54 ± 0.84a	11.99 ± 0.06c	3.79 ± 0.03a	59.02 ± 2.41a	271.69 ± 2.41b
A. digitata						
Raw	10.97 ± 0.40a	12.56 ± 0.45a	18.08 ± 0.10a	2.18 ± 0.03c	56.23 ± 1.25b	267.03 ± 4.00d
2 min	10.80 ± 0.12a	12.80 ± 3.49a	12.78 ± 0.40b	2.56 ± 0.01c	61.06 ± 3.77a	270.60 ± 2.37c
4 min	9.82 ± 1.39a	13.33 ± 1.15a	12.60 ± 0.00b	3.91 ± 0.03b	60.35 ± 0.28a	278.90 ± 0.75b
6 min	7.82 ± 0.22b	14.79 ± 1.51a	8.20 ± 0.28c	4.73 ± 0.04a	64.46 ± 5.96a	289.71 ± 2.34a
V. unguiculata						
Raw	11.17 ± 0.25a	18.00 ± 0.92a	21.96 ± 0.30a	4.23 ± 0.25c	44.64 ± 1.72b	248.35 ± 1.33c
2 min	11.16 ± 0.14a	18.77 ± 0.94a	21.69 ± 0.08a	5.81 ± 0.04b	42.57 ± 0.93b	253.52 ± 2.76b
4 min	11.11 ± 0.15a	19.55 ± 2.47a	20.86 ± 0.12b	6.11 ± 0.01a	42.38 ± 2.76b	253.31 ± 9.43a
6 min	10.79 ± 0.02a	19.68 ± 1.15a	17.09 ± 0.00c	6.43 ± 0.03a	46.01 ± 1.11a	259.77 ± 4.18a
C. patendra						
Raw	25.67 ± 1.12a	31.50 ± 1.50a	15.20 ± 0.05a	1.39 ± 0.22c	26.30 ± 0.11b	142.61 ± 7.74c
2 min	23.90 ± 0.24b	32.44 ± 2.28a	13.29 ± 0.41b	6.62 ± 0.03b	23.67 ± 2.09c	172.34 ± 8.69b
4 min	22.56 ± 0.00b	33.21 ± 1.70a	12.98 ± 0.14c	7.15 ± 0.03a	24.10 ± 2.88c	177.54 ± 7.94b
6 min	21.69 ± 1.56b	33.56 ± 1.09a	7.42 ± 0.00d	7.46 ± 0.05a	29.87 ± 2.70a	187.14 ± 7.48a

Data are represented as Means ± SD (n = 3). Means in the column with no common letter differ significantly ($p<0.05$) for each leafy vegetable.

Indeed, the increased temperature leads to breakage of weak bonds between polysaccharides and the cleavage of glycosidic linkages, which may result in solubilization of the dietary fibres [30]. With regard to their fibres content (12.80 - 32.44%) after 2 min, adequate intake of roasted leafy vegetables could lower the risk of constipation, diabetes, colon and breast cancers [31]. The relatively low values of lipids contents at 2 min of roasting (2.48 – 6.62%) in the studied leafy vegetables corroborate the findings of many authors which showed that leafy vegetables are poor sources of fat [32]. In addition, the estimated calorific values (172.34 – 271.28 kcal/100g) agree with general observation that leafy vegetables have low energy values due to their low crude fat and relatively high level of moisture [33]. Mineral composition of roasted leafy vegetables used in this study is shown in table 2. The residual contents of minerals after 2 min of roasting were significantly different ($p < 0.05$): calcium (294.78 - 879.74 mg/100g), magnesium (175.87 - 480.54 mg/100g), potassium (159.72 - 371.33 mg/100g), iron (15.54 - 84.97 mg/100g) and zinc (13.27 - 38.85 mg/100g). Compared to the values of raw leafy vegetables, these observed reductions may be due to the losses of ashes as observed previously. With regards to these values, the consumption of roasted leafy vegetables (2 min) could cover at least 50% of the standard mineral requirements for human.

Table 2.

Mineral composition of raw and roasted leafy vegetables consumed in Northern Côte d'Ivoire

	Ca	Mg	P	K	Fe	Na	Zn
H. sabdariffa							
Raw	402.21±0.55a	295.93±0.41a	407.59±0.00a	816.19±1.12a	102.08±0.14a	23.46±0.03a	26.06±0.04a
2 min	371.84±2.43b	241.61±1.80b	371.33±5.16b	711.42±3.00b	56.18±3.41b	22.82±0.91a	17.32±9.38b
4 min	368.74±8.90c	111.98±1.53c	232.49±7.70c	629.75±7.23c	35.62±0.35c	21.30±3.81a	12.25±0.31c
6 min	257.32±3.51d	111.85±3.70c	208.79±2.85d	583.76±9.40d	32.43±0.74c	20.05±1.79a	10.12±0.10d
A. hybridus							
Raw	932.6±0.55a	497.75±0.49a	368.69±0.00a	1989.32±2.12a	77.88±0.05a	94.39±0.04a	31.73±0.04a
2 min	879.74±6.44b	480.54±4.74b	366.74±4.36a	1943.57±8.65b	72.57±0.00b	94.38±0.00a	30.11±0.38b
4 min	843.65±0.00c	476.88±0.00c	356.28±0.00b	1826.41±0.00c	68.52±0.58c	94.37±1.33a	26.41±0.00c
6 min	755.01±0.00d	337.24±8.26d	274.86±4.92c	1690.04±1.71d	49.95±3.49d	90.33±5.64b	20.04±0.92d
A. digitata							
Raw	496.26±2.20a	264.36±1.17a	761.63±0.00a	1856.90±8.23a	106.27±0.47a	37.13±0.12a	22.61±0.10a
2 min	464.74±8.39b	175.87±3.74b	275.88±5.54b	1571.84±4.90b	15.54±0.22b	37.00±2.46a	20.68±0.44b
4 min	439.84±4.80c	157.7±2.23c	269.01±3.80c	1496.44±2.14c	15.15±0.32b	35.97±1.36b	12.06±0.14c
6 min	407.66±5.88d	147.35±2.06d	249.03±5.29d	1370.45±6.98d	15.05±2.87b	32.17±1.11c	11.97±0.83c
V. unguiculata							
Raw	439.54±0.56a	341.34±0.18a	309.04±0.00a	718.11±0.91a	91.45±0.12a	33.32±0.02a	40.83±0.04a
2 min	426.94±0.54b	315.39±0.25b	300.02±4.45b	678.50±2.03b	84.97±3.74b	31.75±0.17b	38.85±0.43b
4 min	424.92±5.57c	298.81±2.49c	297.34±0.46c	622.33±2.70c	82.38±0.33b	26.99±1.09c	31.52±0.39c
6 min	417.65±5.36d	293.19±2.46d	293.94±3.69d	549.18±1.44d	78.29±3.56c	25.59±1.07c	23.04±0.02d
C. patendra							
Raw	997.02±0.55a	773.55±0.43a	570.85±2.11a	1585.58±0.87a	219.84±0.12a	42.69±0.02a	35.68±0.02a
2 min	294.78±5.63b	224.82±4.48b	159.72±2.34b	983.00±9.71b	20.74±4.19b	27.96±0.99b	13.27±2.68b
4 min	266.36±9.42c	191.69±0.00c	105.90±0.00c	854.30±0.00c	20.70±0.60b	22.06±4.46c	9.75± 0.00c
6 min	245.09±0.00d	162.08±6.20d	83.27±3.15d	729.74±2.60d	18.11±0.00c	21.08±0.00c	7.78± 0.26d

Data are represented as Means ± SD (n = 3). Means in the column with no common letter differ significantly ($p<0.05$) for each leafy vegetable.

Indeed, these standard requirements are: calcium (1000 mg/day); magnesium (400 mg/day), iron (8 mg/day) and zinc (6 mg/day) [34]. Calcium and phosphorus play important role in growth and maintenance of bones, teeth and muscles [35]. As concern magnesium, this mineral is known to prevent cardiomyopathy, muscle degeneration, growth retardation, congenital malformations and bleeding disorders [36]. Iron plays important role in prevention of anemia while zinc is important for vitamin A and vitamin E metabolism [37,34]. To predict the bioavailability of calcium and iron, anti-nutrients to nutrients ratios of blanched leafy vegetables were calculated (Table 3). The calculated [phytates]/[Ca] ratio in all the roasted species were below the critical level of 2.5 which is known to impair calcium bioavailability [38]. The effect of roasting on anti-nutritional factors (oxalates and phytates) contents is depicted in figure 1. Levels losses ($p < 0.05$) at 2 min were 2.30 – 20.51% and 5.20 – 63.82% for oxalates and phytates, respectively. Oxalates losses increased in the order: *A. hybridus* (2.30%) > *A. digitata* (12.30%) > *V. unguiculata* (13.49%) > *H. sabdariffa* (18.54%) > *C. patendra* (20.51%) while phytates losses increased in the order: *A. digitata* (5.20%) > *V. unguiculata* (20.92%) > *C. patendra* (24.54%) > *A. hybridus* (61.48%) > *H. sabdariffa* (63.82%).The reductions in oxalates and phytates contents during roasting could be advantageous for improving the health status of consumers. Indeed, oxalates and phytates are anti-nutrients which chelate divalent cations such as calcium, magnesium, zinc and iron, thereby reducing their bioavailability [39].

Table 3.

Anti-nutritional factors/mineral ratios of raw and roasted leafy vegetables consumed in Northern Côte d'Ivoire

	Phytates/Ca	Phytates/Fe	Oxalates/Ca
H. sabdariffa			
Raw	0.21	0.85	3.26
2 min	0.08	0.56	2.86
4 min	0.07	0.78	2.71
6 min	0.10	0.80	3.69
A. hybridus			
Raw	0.03	0.41	0.07
2 min	0.01	0.17	0.07
4 min	0.01	0.16	0.06
6 min	0.01	0.18	0.04
A. digitata			
Raw	0.04	0.19	1.57
2 min	0.04	1.21	1.47
4 min	0.03	1.09	1.25
6 min	0.03	0.90	1.11
V. unguiculata			
Raw	0.04	0.19	1.66
2 min	0.03	0.16	1.48
4 min	0.03	0.15	1.35
6 min	0.02	0.11	1.35
C. patendra			
Raw	0.04	0.17	0.78
2 min	0.10	1.39	2.10
4 min	0.09	1.22	1.46
6 min	0.09	1.30	1.34

Roasting also resulted in a decrease of carotenoids and vitamin C contents in the studied leafy vegetables (Figure 2). For carotenoids, losses at 2 min were estimated to 11.24 to 45.16%. Carotenoids losses increased in the order: *A. digitata* (11.24%) > *A. hybridus* (15.28%) > *H. sabdariffa* (17.87%) > *C. patendra* (22.02%) > *V. unguiculata* (45.16%). The decrease in the concentration of total carotenoids could be attributed to the oxidation and isomerization of β-carotene [40]. For vitamin C content, a significant reduction (77.56 - 89.01%) was highlighted after 2 min during roasting processing (Figure 2).

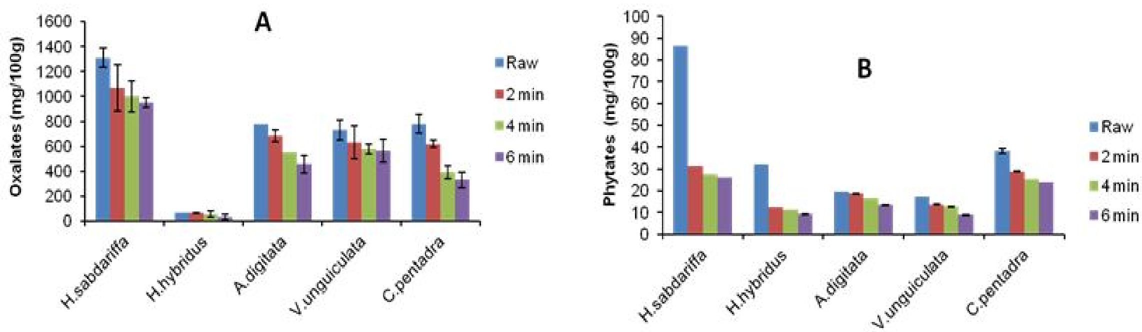

Figure 1: Oxalates (A) and phytates (B) contents of raw and roasted leafy vegetables consumed in Northern Côte d'Ivoire

This decrease in vitamin C could be attributed to the fact that this important micronutrient is not stable at high temperature [41]. With regard to the vitamin C decrease, consumption of roasted leafy vegetables may be supplemented with other sources of vitamin C such as tropical fruits to cover the daily need for humans (40 mg/day) as recommended by food agriculture organization [34].

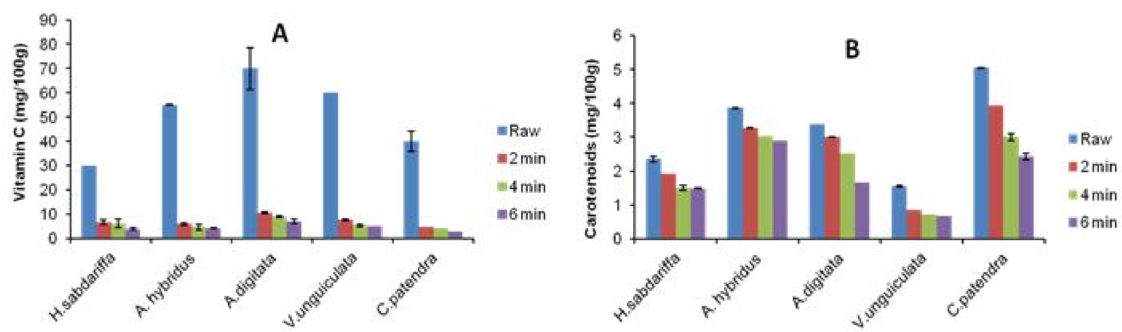

Figure 2: Vitamin C (A) and carotenoids (B) contents of raw and roasted leafy vegetables consumed in Northern Côte d'Ivoire

The effect of roasting on polyphenols content and antioxidant activity of the selected leafy vegetables is depicted in figure 3. It was observed a high increase of polyphenols contents varying from 4.77 to 32.71%. The percent gain in the total phenol content during blanching may be due to the breakdown of tough cell walls and release of phenolic compounds trapped in the fibres of green leafy vegetables [42]. Polyphenols compounds of the roasted leafy vegetables could be advantageous for lower cellular oxidative stress which has been implicated in the pathogenesis of various neurodegenerative diseases, including Alzheimer's disease, Parkinson's disease, and amyotrophic lateral sclerosis [43,44].

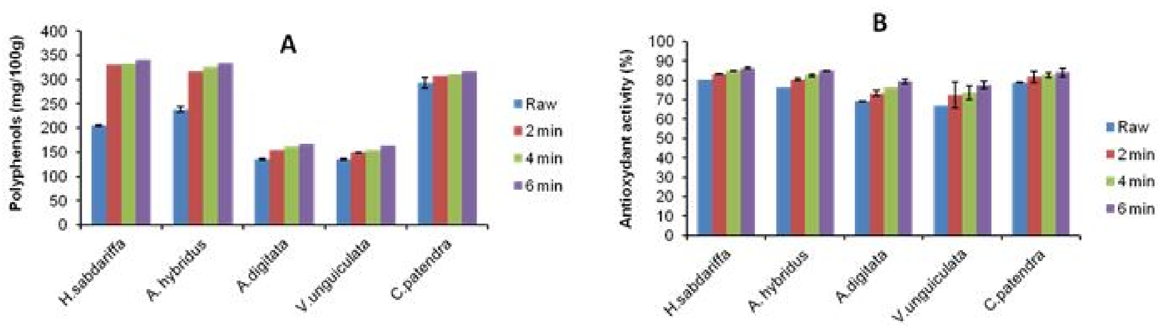

Figure 3: Polyphenols contents (A) and antioxidant activity (B) of raw and roasted leafy vegetables consumed in Northern Côte d'Ivoire

4. Conclusions

Leafy vegetables consumed in Northern Côte d'Ivoire contain significant levels of nutrients that are essential for human health. The present study showed that roasting at 2, 4 and 6 minutes may increase their antioxidant activity and decrease the contents of proteins, mineral, vitamin C, carotenoids, and anti-nutritional factors (oxalates and phytates). The reduction of anti-nutritional factors might have a beneficial effect on bioavailability of minerals like calcium, iron and zinc. Thus, the study suggests that the recommended time of roasting leafy vegetables must be less than 2 min in order to contribute efficiently to the nutritional requirement and to the food security of Ivoirian population.

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