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Effects of cooking methods on the physico-chemical properties, bioactive components and anti-nutritional factors of *Dioscorea alata* L. cultivar "bètè bètè"

Michel Archange Libra[1]*, Sylvie Assoi, Patricia Penan Dehegnan Oulaï[1], Bio Sigui Bruno Bamba[1], Séverin Kouakou Konan[1], Lucien Patrice Kouamé[2]

[1]Laboratory of Biotechnology and Valorization of Agroresources and Natural Substances, Biochemistry and Genetic department, UFR of Biological Sciences, Peleforo Gon Coulibaly University, Box-office 1328 Korhogo (Côte d'Ivoire)
[2]Laboratory of Biocatalysis and Bioprocessing, UFR of Sciences and Food Technologies, Nangui Abrogoua University, PO Box 02 BP 801 Abidjan Côte d'Ivoire.

***Corresponding author: libra_michel_archange@yahoo.fr**
ORCID of corresponding author: 0009-0005-8948-5757

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Abstract: Cooking is a thermal unit operation that causes many changes in food. Thus, this study investigated the effect of two cooking methods (boiling and roasting) on physicochemical properties, bioactive compounds and anti-nutritional factor contents in *Dioscorea alata* cv "bètè-bètè" using standard procedures and methods. Results showed that both methods significantly affected this yam's properties. They resulted in a drop in water content with a slightly acidic pH. In addition, boiling decreased protein content by 36.35% but increased the fiber content by 6.2% more than roasting, while both methods increased the carbohydrate content by 5.45%, and an increase in energy value by 0.59% and 3.17% was observed with boiling and roasting respectively. With the bioactive compounds, a similar decrease in total polyphenol (39.30%) was observed with both methods but the roasting completely degraded the flavonoids although the antioxidant activity was high compared to the rawe. Furthermore, both methods resulted in a similar decrease in phytic acid (2.99%) and oxalate (20%), but the reduction of tannins was 24.53% higher with boiling. For minerals, a decrease in iron, calcium and zinc contents was observed with boiling (16.67%) and roasting (4.81% and 12.5%) respectively. Additionally, a higher increase in potassium (0.89%) and sodium (81.51%) was observed with boiling and roasting respectively. However, roasting increased phosphorus (51.57%) and decreased magnesium (3.16%), whereas boiling decreased phosphorus and increased magnesium. Ultimately, both cooking methods have different effects on the properties of *Dioscorea alata* cv "Bètè-bête", consumers must be aware to choose the one that suits their needs.

Keywords: Cooking, Boiling, Roasting, Proximal composition, Yam, bioactive compounds.

Introduction

Yam is a climbing herbaceous plant belonging to the family Dioscoreaceae and genus Dioscorea, containing more than 600 species (Kumari *et al.* 2025). It is widely cultivated in many tropical and subtropical regions in the world for its tubers, which are used as a staple food. Notable varieties including the complex *D. cayenensis-rotundata*, *D. alata*, *D. dumetorum*, *D. esculenta* and *D. bulbifera* are cultivated mainly in Côte d'Ivoire and other West Africa countries (Bakayoko *et al.*, 2017). This area, known as the "Yam Belt", accounts for more than 95% of world production, with the main producers being Nigeria (61.92 million tons), Ghana (10.51 million tons), Côte d'Ivoire (7.96 million tons) and Benin (3.32 million tons) (FAO, 2024). Yam tuber is an excellent source of starch providing caloric energy (Induar *et al.* 2024; Jahan *et al.* 2020; Chandrasekara & Kumar, 2016). It also provides protein, low fat, fibre, vitamins and minerals such as potassium, calcium, magnesium and iron. In addition, it contains bioactive compounds (flavonoids, polyphenols and tannins) which are antioxidants with physiological effects, and minor antinutritional factors such as phytate and oxalic acid (Godfrey *et al.*, 2023; Lavlinesia *et al.*, 2023, Lombe *et al.*, 2023). Among the main cultivated species, *Dioscorea alata* is remarkable for its wide distribution in the tropics, its variability and its economic value, making it probably the most representative yam species (Tokpa & Sery, 2023). In Côte d'Ivoire, "bètè-bètè" variety is an important food crop for people living in the central, eastern and northern regions. This variety, belonging to late yams category, is cultivated from March to April and harvested in December when reaching senescence and complete dryness. It produces a single grey tuber weighing up to one kg (Meena *et al.*, 2018) which serves as staple food for these populations after cooking. Several cooking methods are used, the most common being boiling and roasting. On the one hand, the boiled yam, called "akpessi", is eaten with or without a sauce consisting of a pasty mixture of African aubergines, smoked fish and chilli with or without oil, or crushed to obtain a sticky paste called "yam foutou" consumed with several sauces. On the other hand, roasted yam is eaten with chilli powder. However, both methods are thermal unit operations that affect the physico-chemical and functional properties, bioactive compounds, and mineral content of yam (Putri *et al.*, 2025; Adinsi *et al.* 2023; Otegbayo *et al.*, 2023). However, most of the previous studies conducted on yams have focused on the “kponan” variety. Consequently, there is little data on the “bété bête” variety. Thus, this study aimed to analyze the effect of the two common methods, boiling and roasting, on the qualitative attributes of *D. alata* yam “bètè bètè” variety.

Results

pH and titratable acidity

The pH and titratable acidity of raw, boiled, and roasted yam flour of *Dioscorea alata* cv “bètè bètè” are presented in Table 1. The results showed that pH value yam flours are slightly acidic ranging from 5.17±0.01 to 5.25±0.01. In addition, boiling and roasting did not significantly decrease pH value.

The titratable acidity (AT) of yam flour ranged from 15.33±1.50 to 19.00±3.00meq/100g. Despite the slight decrease in TA observed with boiling (15.33±1.50meq/100g), the results showed that the TA of these three flours did not differ significantly.

Proximate composition

The proximal composition of yam flour is shown in Table 2. The cooking method resulted in a significant decrease in moisture content ($p < 0.05$). The greatest moisture content (12.97±0.06%) was observed with raw yam flour, followed by boiled yam flour (11.79 ± 0.04%) and then roasted yam flour (10.11±0.12%).

The “bètè bètè” yam flour showed an ash content value ranging from 2.61 ± 0.02% to 2.93 ± 0.01 %, with raw yam flour having the lowest value. The increase in ash content was higher with roasting (2.93±0.01%) than boiling (2.88±0.01%).

The protein content of “bètè bètè” yam flour ranged from 2.25±0.06 to 5.75±0.06%, with raw yam flour having the highest value. In addition, the yam protein content decreased significantly with boiling (2.25±0.06%) than with roasting (4.34±0.00%). However, lipid content did not affect by both treatments applied and very low (0.20±0.00%).

The fibre content of the yam ranged from 5.00±0.35% to 5.33±0.21%. The raw yam flour content was 5.00±0.35%. It was found that cooking did not significantly affect fibre content.

From Table 2, I can be found that “bètè bètè” yam flour carbohydrate contents were high, with values ranging from 73.61±0.03 to 77.72±0.02%. Both cooking methods applied resulted in a significantly increase in carbohydrate content when compared raw yam flour (73.61±0.03%). However, the carbohydrate content was similar for both methods.

The energy of “bètè bètè” yam flour ranged from 317.78±0.04 to 327.84±0.46 Kcal. In addition, roasting resulted in greater increase in energy content (327.84±0.46 Kcal) than boiling (319.67±0.60 Kcal). Raw yam flour energy was the lowest (317.78±0.04 Kcal).

Mineral content

Table 3 shows the variability of macro and micro minerals in "bètè bètè" yam flour. Among microminerals in raw yam flour, calcium content was the highest (2308.75±0.06mg/100g) followed by potassium (999.67±1.24 mg/100g), magnesium (262.5±7.00mg/100g), phosphorus (232.7±02.00 mg/100g), and sodium (1.95±0.05mg/100g). Microminerals including iron and zinc content were found to be 0.60±0.00 mg/100g and 0.40±0.00mg/100g respectively. However, cooking yam resulted in a significant change in mineral contents ($p < 0.05$). Both methods decreased calcium contents with roasting showing a greater decrease (2086.34±0.04 mg/ 100g) than boiling (2197.30±5.00 mg/100g), while potassium content was similarly increased after these two treatments (1090.00±4.00mg/100g). However, boiling significantly increased (303.70±5.00mg/100g) yam magnesium content, while roasting decreased its (254.2 ± 0.01 mg/100g). In addition, phosphorus content was significantly decreased and increased when applied roasting (352.70±1.00mg/100g) and boiling (213.30±0.50 mg/100g) respectively. In addition, the sodium content of treated yam flour was found to be significantly higher than that of the raw yam flour (1.95±0.05mg/100g), roasting showing the greatest value (4.04±0.03mg/100g) than boiling (2.47±0.05mg/100g). Concerning micro mineral content, it can be found that iron and zinc contents of the yam flour were reduced by applied treatments. boiling resulted in greater reduction of iron (0.24±0.00 mg/100g) and lower reduction of zinc (0.33±0.00mg/100g) while roasting resulted in greater reduction of zinc (0.28±0.00mg/ 100g) and lower reduction of iron content (0.34±0.00mg/100g).

Bioactive and anti-nutritional factors contents

Bioactive compounds contents of “bètè bètè” yam flour were also affected by the cooking methods applied. As far as concerned total polyphenol content, a significant reduction difference ($p < 0.05$) was observed with roasting and boiling compared to raw yam flour which showed the highest value of content (45.11±3.99mg GAE/100g MS). The total polyphenol content values of roasted and boiled yams were similar. However, while flavonoids content was significantly increasing with boiling (5.74±3.49 mg QE/100g DM; $p < 0.05$), flavonoids were indetectable with roasting. In contrast, antioxidant activity was significantly increased with both cooking methods which showed similar value (35.27meq/100g) trend as compared to raw yam flour (28.90±0.46meq/100g).

The anti-nutritional factors contents of "bètè bètè" yam flour were significantly reduced following the application of treatments. For oxalate and phytate, the content values were similar between boiling and roasting which were about 95.43 and 256.67mg/100g as compared to raw (98.38±0.16 and 322.67±45.80mg/100g respectively). Regarding tannin, boiling greatly reduced the content (93.57±5.81mg TAE/100 g) than roasting (126.05±3.65 81mg TAE/100g).

Discussion

The results showed that cooking did not significantly affected pH as compared to raw yam flours. The pH was slightly acid with a value of 5.22. The results observed in this study were closer to those reported by Ogliari *et al.* (2020) for raw sweet potatoes (5.49±0.06), boiled sweet potatoes (5.86±0.01) and baked sweet potatoes (5.61±0.06). The acidic pH not only ensures the microbiological safety of roasted and cooked yams but also improves their techno-functional properties (Munch-Andersen *et al*., 2024; Alfaris *et al*., 2022). On the other hand, only boiling significantly reduces the titratable acidity. These results are consistent with those of Tsai *et al* (2021), who also observed a decrease in titratable acidity after cooking.

Roasting resulted in a greater reduction in moisture content than boiling as compared to raw yam flour. This may be explained by the higher rate of water transfer due to the higher heat transfer during roasting. When roasting, heat is transferred to the product, which increases pressure in the cells. Subsequently, the cells explode, and the water is transferred to the outside, resulting in a decrease in the amount of water in the yam. (authors here).

The protein content (5.75±0.06%) of raw yam was higher than the results obtained by Kimbonguila *et al*. (2019), but lower than the value (9.03±0.20%) reported by Nwafur *et al*. (2020) for water yam. The difference may be due to the variety. However, cooking significantly

Table 1. pH and titratable acidity of raw, boiled and roasted *Dioscorea alata* cv "bètè bètè" yam flour.

	Raw yam	Boiled yam	Roasted yam
pH	5.22 ± 0.02^{b}	5.25 ± 0.05^{b}	5.17 ± 0.03^{a}
Titratable acidity (meq/100g)	19.00 ± 3.00^{a}	15.33 ± 1.50^{a}	18.67 ± 3.06^{a}

Different superscripts on the same line indicate significant difference by the Tukey's test (p < 0.05).

Table 2. Proximate composition of raw, boiled and roasted of *Dioscorea alata* cv "bètè bètè" yam flour.

Composition (%)	Raw yam	Boiled yam	Roasted yam
Moisture	12.97 ± 0.06^{c}	11.79 ± 0.04^{b}	10.11 ± 0.12^{a}
Proteins	5.75 ± 0.06^{c}	2.25 ± 0.06^{a}	4.34 ± 0.07^{b}
Lipids	0.2 ± 0.00^{a}	0.2 ± 0.00^{a}	0.2 ± 0.00^{a}
Fibres	5.00 ± 0.35^{a}	5.33 ± 0.21^{a}	5.02 ± 0.33^{a}
Ash	2.61 ± 0.02^{a}	2.88 ± 0.01^{b}	2.93 ± 0.01^{c}
Carbohydrate	73.61 ± 0.03^{a}	77.72 ± 0.02^{b}	77.53 ± 0.12^{b}
Energy (Kcal)	317.78 ± 0.04^{a}	319.67 ± 0.60^{b}	327.84 ± 0.46^{c}

Different superscripts on the same line indicate significant difference by the Tukey's test (p < 0.05).

Table 3. Minerals content of raw, boiled and roasted *Dioscorea alata* cv "bètè bètè" yam flour.

Mineral (mg/100g)	Raw yam	Boiled yam	Roasted yam
Potassium (K)	999.67 ± 1.24^{a}	1090.00 ± 4.00^{b}	1081.11 ± 5.0^{b}
Phosphorus (P)	232.7 ± 02.00^{b}	213.30 ± 0.50^{a}	352.70 ± 1.00^{c}
Calcium (Ca)	2308.75 ± 0.06^{c}	2197.30 ± 5.00^{b}	2086.34 ± 0.04^{a}
Magnesium (Mg)	262.5 ± 7.00^{b}	303.70 ± 5.00^{c}	254.2 ± 0.01^{a}
Sodium (Na)	1.95 ± 0.05^{a}	2.47 ± 0.05^{b}	4.04 ± 0.03^{c}
Iron (Fe)	0.60 ± 0.00^{c}	0.24 ± 0.00^{a}	0.34 ± 0.00^{b}
Zinc (Zn)	0.40 ± 0.00^{c}	0.33 ± 0.00^{b}	0.28 ± 0.00^{a}

Different superscripts on the same line indicate significant difference by the Tukey's test (p < 0.05).

Table 4. Anti-nutritional factors and Bioactive contents of raw, boiled and roasted *Dioscorea alata* cv "bètè bètè" yam.

	Raw yam	Boiled yam	Roasted yam
Anti-nutritional factors			
Phytic acid (mg/100 g DM)	98.38 ± 0.16^{b}	95.43 ± 0.99^{a}	96.57 ± 0.00^{a}
Oxalate (mg/100 g DM)	322.67 ± 45.80^{b}	256.67 ± 33.61^{a}	244.20 ± 34.29^{a}
Tannins (mg TAE/100 g DM)	138.05 ± 9.69^{c}	93.57 ± 5.81^{a}	126.05 ± 3.65^{b}
Bioactive components			
Total polyphenols (mg GAE/ 100 g DM)	45.11 ± 3.09^{b}	27.38 ± 2.18^{a}	31.68 ± 3.03^{a}
Flavonoids (mg QE/ 100 g DM)	3.04 ± 0.75^{b}	5.74 ± 0.49^{c}	0.00^{a}
Antioxidant activity (meq/100g)	28.90 ± 0.46^{a}	35.27 ± 0.87^{b}	35.87 ± 0.90^{b}

Different superscripts on the same line indicate significant difference by the Tukey's test (p < 0.05).

decrease (P < 0.05) the protein contents. The greater decrease in protein was found with boiling than roasting. Similar results were reported by Fang *et al.* (2022) for boiled and baked potatoes. Indeed, the observed decrease in protein content should be due to the coagulation of proteins linked to the heat treatment, which makes it more difficult to be extracted. This is certainly more pronounced in the case of boiling, which has resulted in a low protein content in boiled yam.

The carbohydrate content increased significantly (P < 0.05) in boiled and roasted yam in the same way compared with raw yam. This could be attributed to either thermal hydrolysis of the long chain of carbohydrates or release of amylose and amylopectin from swelling and bursting of starch granules during heat treatment (Sriroth *et al.*, 1999; Nguyen *et al.*, 2015). However, fibre content was not significantly affected by the different cooking methods, suggesting that yam fibre is resistant to the cooking conditions used. Indeed, Oke et *al.* (2021) pointed out that dietary fibres are insoluble and stable to heat treatments.

The lipid content of raw yam flour (0.2±0.00%) was lower than the value (0.75 ± 0.2%) obtained by Fang *et al.* (2022) for potatoes of different varieties. However, in this study, cooking (boiling and roasting) did not affect oil content. This observation is in line with the results reported by Kenfack *et al.* (2021), who observed no significant difference between the lipid content obtained with raw, boiled and roasted wild yam (*Dioscorea praehensilis* Benth). In contrast, ours result contradicts those of Cheong *et al.* (2022) who observed a decrease and an increase in lipid content in boiled and baked potato flour, respectively. This suggests that the lipid content is related to the variety of tubers used.

The ash content increased significantly with boiling and roasting compared to raw yams. Indeed, the increase in ash content could be attributed to the contamination of the coal deposits during roasting, also to the contamination of the debris from the cooking container, a lower humidity of the cooking and the fineness of the cooked yam flour which has favoured the completion of the combustion in the muffle furnace, resulting in a higher ash content.

Concerning macronutrients, cooking process resulted in an increase in sodium and potassium contents, especially during roasting. This increase could be due to radiation from charcoal combustion (Adeniji *et al.*, 2007). On the other hand, potassium and calcium content significantly decrease could attributed to leaching (Adegunwa *et al.*, 2011). However, magnesium and phosphorus contents did not change significantly regardless of cooking method, suggesting that boiling and roasting have preserved these minerals. These results are consistent with those obtained by Sanful and Darko (2010). Regarding micronutrients, the results showed a significant decrease in iron

and zinc contents with boiling. This reduction can be explained by the leaching of minerals caused by boiling, resulting in a greater loss of these micronutrients (Fang *et al.*, 2022). In contrast, roasting did not significantly affect mineral contents (Napitupulu *et al*., 2013).
With regard to bioactive compounds, total polyphenol levels decreased significantly with roasting and boiling which may be due to the degradation effect of heat on these compounds (Kenfack *et al.* 2021). However, flavonoid content increased significantly with boiling but was not detected in the roasted yam. This absence of flavonoids in roasted yam suggests roasting degraded these compounds (Sanful & Darko, 2010). Additionally, antioxidant activity increase with boiling and roasting. This could be related to the release, formation and transformation of antioxidant compounds during the cooking process, which may enhance its overall antioxidant activity (Duan *et al*., 2021).
For antinutritional factors, phytates and oxalates contents are found to decreased with the different cooking processes. In fact, during the boiling and roasting processes, these substances are eliminated by leaching and evaporation, respectively (Kenfack *et al.* 2021). Likewise, Ezeocha & Ojimelukwe (2012) indicated these compounds decreased during roasting and boiling because of the thermal degradation.

Material and methods

Plant material
The yams used were tubers of *Dioscora alata* cv "Bètè bètè" freshly harvested from farmers in the region of Lataha (Korhogo, northern Côte d'Ivoire) in December 2023.

Preparation of yam flour
The flours were prepared using the raw, boiled and roasted yam flour processing method described by Razanamparany (2003). Yam tubers were sorted and washed with tap water to remove soil and plant debris, then drained for an hour. Drained samples were divided into three batches. The first batch, considered as blank, was peeled, washed in tap water and sliced into small pieces with a stainless-steel knife. The second and third batches after undergone the same treatments as the blank were boiled in boiling water for 20min and roasted for 2 hours in a local hand-made roaster respectively. After treatment, these batches were spread separately on aluminium foil and then oven-dried at 45°C for 72 hours. After drying, the samples were ground using a Moulinex (France) blender, sieved 250µm in diameter and stored in clean, airtight containers for further analysis.

Proximate analysis
Standard methods of the Association of Official Analytical Chemists (AOAC, 2005) were used to determine the moisture content, crude protein content, lipids content, ash content and crude fibre of the treated yam flours.

Moisture content
The moisture content was gravimetrically determined by oven-drying 2 g of each sample in a crucible at 105°C to a constant weight.

Crude protein content
The crude protein content was determined by multiplying the nitrogen content obtained using Kjeldahl method by 6.25.

Lipids content
The crude fat content was gravimetrically determined after extraction using anhydrous hexane in a Soxhlet apparatus.

Ash content
The ash content was gravimetrically determined by after ashing 3 g of flour in porcelain in a muffle furnace at 550°C for 6 h.

Crude fibre content
The crude fibre content was gravimetrically determined after incineration of the digestion residue from 2g of flour in H_2SO_4 in a muffle furnace at 550°C for 6 hours.

Carbohydrate content
The carbohydrate content was determined by deduction using the following equation:
Carbohydrate (%) = 100 - (% Moisture + % Crude protein + % Crude fat + % Ash + % Fibre).

Energy (Kilo calories)
Energy was determined using the calculation method of Udosen (1995) which consists in multiplying the mean values of lipids, proteins and carbohydrates by 9,4 and 4 respectively.
Mineral analysis
Minerals were determined using the method reported by Oshodi (1992). To do this, 1g of flour was dissolved in a 10% solution of HCl, then filtered and the volume was adjusted to 40mL with deionized water. The filtrate was then used to determine sodium and potassium contents by the flame photometry method (AOAC, 2005), calcium, iron, manganese, zinc, copper and magnesium contents by Atomic Absorption Spectrophotometry (SAA) and phosphorus content by calorimetry (UV-visible spectrophotometer, model DR 2800/USA).

Anti-nutritional factors and Bioactive components

Extraction process of compounds
The extraction of compounds was carried out according to the method described by Mallek-Ayadi (2019). A sample of 4 g of flour was dissolved in 2mL of n-hexane and 4mL of methanol/water (60/40). After vortex stirring, the suspension was centrifuged at 5000 rpm for 3 min and the pellet was taken up again for a second extraction according to the same procedure. The supernatants were combined, washed with 4 mL of n-hexane to remove oil residue and then concentrated using a rotary evaporator.

Total polyphenolic content
Total polyphenols content was determined using the Folin-Ciocalteu reagent method described by Yoo *et al.* (2004). 2.5mL of the diluted Folin-Ciocalteu reagent (1/10) was added to 5 ml phenolic extract. After stirring, the mixture was left to stand in the dark for 3 minutes. In addition, 1.5ml of 20% Na_2CO_3 was added to the mixture, shaken and then incubated in dark at room temperature for 30 minutes. The absorbance was measured at 517 nm using a spectrophotometer (Shimadzu, Japan). Gallic acid was used as a standard and the results were expressed in milligrams of equivalent gallic acid per 100g of extract (mg GAE/100g DM).

Phytates
Phytate content was determined according to the method described by Zebib *et al.* (2015). Briefly, 0.25g of flour was added to 12.5mL of hydrochloric acid (3%). The mixture was then placed in a water bath at 30°C for 45minutes. After incubation, the mixture was centrifuged at 4000 rpm for 10 minutes. To the supernatant solution, 4mL of $FeCl_3 \cdot 6H_2O$ were added, and the absorbance of the resulting mixture was read at 822 nm using a spectrophotometer.

Tannins
The tannin content was determined by the method of Trease and Evans (1978). One mL extract was mixed in a 5mL of Folin-Dennis reagent in an alkaline medium. The absorbance of the mixture was read at 760nm, and the tannin content was determined using a standard curve constructed from a range of tannic acid concentrations.

Oxalic acid
Oxalic acid content was determined by the $KMnO_4$ method as described by AOAC (2005). One (1) gram of flour was dissolved in 75mL of sulfuric acid 15N. The mixture was homogenized for one hour and filtered on Whatman paper No. 1.25mL of the filtrated solution was titrated with 0.005M of potassium permanganate.

Statistical Analysis

All experiments were performed in triplicate and the results are expressed as means ± standard deviations. One-way analysis of variance (ANOVA) and Tukey's post-hoc test were used to determine significant differences between means at significance level of 0.05 ($p < 0.05$) using Statistica software (version 7.1).

Conclusion

The present study was carried out to evaluate the effects of two common cooking methods (boiling and roasting) *on Dioscorea alata* cv "Bètè-bètè" when comparing to the raw sample. It was noted that raw yams contain carbohydrates, proteins, fibres, ash and minerals such as potassium, calcium, magnesium and phosphorus but also anti-nutritional factors (tannins, phytates, oxalic acid) and bioactive compounds (polyphenols, flavonoids). However, both cooking methods differently affect the resulted yam flours. They positively reduce anti-nutritional factors content making suitable for consumption, and improved bioavailability of certain nutrients. However, they unfortunately cause the reduction of some nutritional compounds. Consumers must therefore be aware of the impact of these methods on this variety of yam so that they can choose the one that best meets their needs.

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Conflict of interest
The authors declare no conflicts of interest

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Writing-original draft:
Michel Archange Libra, Sylvie Assoi, Patricia Penan Dehegnan Oulaï, Konan Sévérin, Bio Sigui Bruno Bamba

Writing-review and editing:
Michel Archange Libra, Sylvie Assoi, Bio Sigui Bruno Bamba, Patricia Penan Dehegnan Oulaï.

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