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Chemical Composition and Hydration Index of Selected Cooked Foods Consumed in Kisangani, Democratic Republic of the Congo: An Approach to Improve Dietary Prescription in Patients

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Abstract

Dietary management of diet-related non-communicable diseases requires prior knowledge of the caregiver on the chemical composition of foods. The objective of this study is to determine the approximate chemical composition, yield factors (YF), yield coefficient (YC) and edible coefficient (EC) of some staple foods after cooking consumed in Kisangani, in order to improve the dietary prescription of patients. **Methods:** This was a quasi-experimental study carried out in Kisangani. Sweet cassava (*Manihot esculenta* Crantz) and its processed products, sweet potatoes (*Ipomoea batatas*), Bananas (*Musa paradisiaca*), taros (*Colocasia esculenta*), flour pastes (foufou) of corn (*Zea maize*), cassava and semolina, as well as rice (*Oryza sativa* L.) were analyzed for their approximate chemical composition after cooking, yield factors (YF), yield coefficient (YC) and edible coefficient (EC). Chemical analyses were carried out at the biochemistry laboratory of the Faculty Institute of Agronomic Sciences of Yangambi (IFA) between March 2022 and August 2023. **Results:** The plantain cultivar French has an EC of 48.68 ± 1.90 significantly higher than the other varieties ($P < 0.05$), its YF after peeling is low (0.51 ± 0.02) or 51% of edible part, the water absorption was on average 61.17% for rice, 65.45% for pasta (foufou) and 9.62% for tubers and bananas. The moisture, carbohydrate and energy content for the three food groups (rice, tubers/bananas and flour pasta) were not significantly different after cooking. **Conclusion:** Only the chemical composition of foods after cooking should be considered during dietary prescription. The use of chemical composition of raw foods could overestimate or underestimate the patient's nutritional intake. It is therefore recommended that providers refer to the chemical composition of foods after cooking when prescribing dietetics.

Keywords

Chemical Composition of Foods, Dietetic Prescription, Kisangani, DRC

1. Introduction

Diseases related to poor nutrition, such as malnutrition and metabolic diseases, are on the rise in the Democratic Republic of the Congo (DRC). Approximately 44.7% of children under five suffer from chronic malnutrition and 7.2% from acute malnutrition [1]. In some cities in the DRC, the prevalence of diabetes mellitus ranges from 4.8% to 8.4%, and reaches 14.9% for hypertension [2]-[4]. Dietary prescription is important for the proper management of diet-related non-communicable diseases. However, proper prescription requires the provider's knowledge of the chemical composition of cooked foods, given that the food is served to the patient cooked [5].

In the city of Kisangani, dietary prescriptions are based on data from the chemical composition table for raw foods, as the chemical composition table for cooked foods remains incomplete. However, it has been reported that the cooking method influences the chemical composition of foods [6]. During boiling, nutrients are absorbed into the water, and large quantities of soluble materials (amino acids, minerals, sugars and oligosaccharides, short-chain fatty acids, etc.) are thus exchanged; some are extracted, others are introduced into the food, which either hydrates or dehydrates [7] [8]. The chemical composition of foods after cooking is determined either by direct analysis of samples or by calculations using yield factors and retention factors [9].

Cereals and tubers are cooked primarily by boiling in Kisangani households. Roots and tubers are first washed and peeled, a process that reduces the initial weight of the food, thus requiring the determination of the edible coefficient (EC). Cooking therefore constitutes the last processing step for certain foods before consumption [10]. Therefore, the objective of this study was to determine the proximate composition of selected staple foods after cooking as well as to determine the yield factors (YF), yield coefficient (YC) and edible coefficient (EC) in order to improve the dietary prescription of patients.

2. Material and Methods

2.1. Study Area

This study was conducted in the city of Kisangani, Tshopo Province, in the Northeastern of the DRC. The chemical composition analyses conducted in the biochemistry laboratory of the Yangambi Faculty of Agricultural Sciences (IFA-Yangambi).

2.2. Study Design and Period

This descriptive and quasi-experimental study was conducted between March 2022 and August 2023, during which time the analyses were performed in the laboratory.

2.3. Collection of Experimental Samples

The samples of Sweet cassava (*Manihot esculenta* Crantz), white and yellow fleshed sweet potato (*Ipomoea batatas*); and two species of taro (*Colocasia esculenta*): the large taro (*Manyango*) and the small taro (*Xanthosoma*) locally called *Maole*, yellow corn (*Zea maize*) flour, semolina, unripe plantain banana (*Musa paradisiaca*) *faux-corne* and *French* varieties, unripe dessert banana (*Musa acuminata balbisiana*), unripe Bisamunyu banana (*Musa* sp), and rice samples (*Oryza sativa* L.) were collected from Kisangani city local market. The medium grains brown rice, large grains brown rice, white rice with small grains, large grains white rice and imported rice were obtained from Opala, Bumba, Bamanga, Yafira villages and Holland, respectively. The selection of these foods was based on the fact that they are the staple and most consumed foods by the population of Kisangani and its surroundings area. All the foods analyzed were purchased in bulk at the central market and small markets in the city of Kisangani. We purchased five piles of each of the foods (sweet cassava tubers, sweet potatoes (SP) and taro) freshly harvested from farms. After mixing these five piles for each of these foods, we randomly selected 4 to 7 tubers weighing about 1.5 kg which were used in the experiment.

2.4. Sample Preparation and Processing/Cooking

Sweet cassava, sweet potatoes, taro, and bananas samples: About 1.5 kg for each food; Sweet cassava, sweet potatoes, taro, and bananas, were washed in clean tap water, cut into portions and weighed (P1), peeled and reweighed (P2), then each peeled portion, 40 g (which is the average weight of fried cassava portion sold in Kisangani market) were weighed and numbered then boiled. Cooking time was calculated from the moment the water began to boil. Cooking was confirmed by the consistency of the tuber becoming soft. After cooking, the samples were left at room temperature, drained, and reweighed (P3) using an electronic balance (Model SF-400 China) with 10 kg capacity. A portion was then pounded using a locally made wooden mortar and pestle, for moisture determination. Another portion of the samples was first oven-dried (MARC Technologies made in Australia) at 60˚C for 24 hours; then pounded in mortars, the resulting powder was used to determine the proximate chemical composition of foods according to procedure followed by François *et al.* [11].

***Preparation of chikwangue* (*cassava stick*):** The cassava tubers were peeled, soaked in water for 5 days, then washed and stripped of fibers. They were then pounded in a mortar to obtain a retted cassava paste. Two cooking methods were used: 1) one-stage cooking (*chikwangue Topoke*), the retted cassava paste was immediately wrapped in leaves and tied with string after shaping, and then cooked in water for 48 minutes. 2) two-stage cooking (*chikwangue Bingwele*), the retted cassava paste was pounded in a mortar, soaked in water, defibrated using a sieve, and then decanted for 2 hours. After the water was removed, the remaining starch was poured into a bag and drained for 12 hours. Then, the resulting paste was cooked in boiling water for about 20 minutes and latter pounded in a mortar. Then, it was wrapped in leaves after shaping and cooked in water for 1 hour. The cooked *chikwangue Bingwele* was taken kept for 12 hours after cooking, and well cooled.

***Fried cassava* (*molecule*):** Approximately 1.5 kg of fresh tubers were peeled, cut into small 40 g pieces (P1). As locally procedure, they were pan-fried in 400 ml of preheated palm oil 160˚C to 180˚C for 15 minutes, then cooled and reweighed (P2) as described by Jinglin *et al.* [12].

***Cassava puree* (*Masele*):** it consists of a traditional method of cooking, about 3 kg of tubers were boiled in water without peeling for 35 minutes. After cooking, the tubers were peeled, grated, washed in water, and then wrapped in leaves.

Rice cooking: Approximately 1500 mL of water was measured and then boiled in a pot whose weight was previously measured and recorded. Then, 500 g of rice, previously winnowed and sorted, were weighed using an electronic scale (brand Tanita Lot No. P80120 made in China with a capacity of 5 kg) and immersed in boiling water. The rice was subject to continuous monitoring for softening. Afterwards, a quantity of water was removed, measured and recorded. Then, the rice was covered with a bag and a lid until completely cooked. The cooked rice was exposed to an ambient atmosphere for cooling, after which, the pot containing the rice was reweighed. The net weight of rice was equal to the weight of the pot containing the cooked rice minus the weight of the empty pot. The quantity of water used was obtained by taking the difference between the quantities of water measured before cooking minus the remaining quantity. The cooking time used was ranged from 29 - 43 minutes. A portion of rice was taken for moisture determination while the remaining one was first oven-dried (MARC Technologies made in Australia) at 60˚C for 24 hours; then pounded with a wooden mortar to obtain the powder that was used for the determination of crude protein, crude ash, carbohydrates, crude fiber, and lipids.

***Preparation of cassava, corn, and semolina-based paste* (*foufou*):** Three samples of *foufou* using cassava flour, yellow corn flour, and semolina were prepared. Another fourth and fifth fufu samples were also prepared by substituting 50% of the cassava flour with yellow corn and semolina flour. About 1000 mL of water placed in a previously weighed pot and then heated; after boiling, a quantity of hot water was reduced, then 250 g of the flour was put in the water and kneaded until the dough gelatinized by gradually adding water. The remaining water was remeasured. The quantity of water used was estimated by taking the difference between the quantity that was heated and the remaining quantity after baking. Baking time was estimated from the moment the flour was mixed with boiling water. The net weight of the paste was equal to the weight of the pot containing the paste minus the weight of the empty pot. After baking, a portion of the paste was taken for moisture determination. Another portion was first oven-dried (MARC Technologies made in Australia) at 60˚C for 24 hours; then pounded. This constituted the sample for the determination of crude protein, crude ash, crude fiber, and lipids and carbohydrates.

2.5. Edible Coefficient, Water Absorption Rate, Yield Factor, and Yield Coefficient

Edible coefficient* (*EC*) *or loss rate: It expresses the percentage of weight loss due to waste removal. This coefficient was calculated for tubers and bananas. It was determined using the method described by FAO [13] as shown in formula (1):

$$\text{EC} = \frac{P1 - P2}{P1} \times 100 \tag{1}$$

where $P1$ = weight of the sample before peeling, $P2$ = weight after waste removal.

***Yield Factors* (YF) *and Yield Coefficient* (YC):** For samples with waste, the yield factor after waste removal was determined based on formula (2) and the yield coefficient by the formula (3).

$$\text{YF} = \frac{\text{Weight of a portion of food after peeling}}{\text{Weight of the sample before peeling}} \tag{2}$$

$$\text{YC} = \frac{\text{Weight of an edible portion of food before peeling}}{\text{Weight of the portion after peeling}} \tag{3}$$

For samples without waste, the yield factor and yield coefficients factor were determined after cooking according to the formula described by Bognâr [6] and presented in formula (4) for the YF and formula (5), respectively as presented below.

$$\text{YF} = \frac{V(k, p)}{U(k)} \tag{4}$$

where $V(k, p)$ = quantity of food k prepared by method p in grams. $U(k)$ = portion of fresh food ready to be prepared without adding water or oil

$$\text{YC} = \frac{\text{Weight of an edible portion of a food before cooking}}{\text{Weight of the portion after cooking}} \tag{5}$$

Water absorption rate: The protocol for water absorption and cooking time were adapted from Kouadio *et al.* [14] and Wheatley & Gómez [15], respectively, with a slight modification on the weight of the sample before cooking as presented in formula (6). The cooking time for tubers and banana was determined to the nearest minute by the ease of penetration with a common fork on the sample.

$$\text{Water absorption rate} = \frac{P2 - P1}{P2} \tag{6}$$

where: $P2$: weight of a portion of food after cooking; $P1$: Weight of a portion of food before cooking.

2.6. Proximate Chemical Composition Analysis

The proximate chemical compositions of the foods: moisture, crude ash, crude fiber, fat, and protein) were determined using standard AOAC analytical procedures [16], and carbohydrates were determined by the difference [e.g., 100 − (% moisture + % protein + % fiber + % ash + % fat)] [17]. Energy was estimated using the relationship between fat, carbohydrate, and protein contents of the Atwater conversion factors: (4 Kcal/g) for protein, (4 Kcal/g) for carbohydrates, and (9 Kcal/g) for fat [18].

2.7. Statistical Analysis

All data were collected in triplicate. Mean values ± standard deviation (SD) were calculated, and the data were subjected to analysis of variance (ANOVA). Post-hoc analysis was performed using Tukey's Honestly Significant Difference (HSD) after verification of the normality using the Statistical Analytical Software (STATA) version 10. When a significant F-test was noted, significance was accepted at $P < 0.05$. Results were expressed as mean values ± standard deviation of triplicate determinations. Samples were classified into three groups according to their cooking method; e.g., 1) rice, 2) flour (cassava and corn), and 3) tuber and banana. The foods were compared in terms of their water absorption rates during cooking and their proximate chemical compositions.

2.8. Limitation of the Study

Only foods cooked by boiling, a traditional method of preparation, were analyzed, except for sweet cassava, which was also analyzed by frying.

3. Results

3.1. Edible Coefficient and Yield Factor

Table 1 presents the EC or waste rate, the YC, and YF of sweet cassava, taro, bananas, and sweet potatoes before cooking. The statistical result shows that the French plantain cultivar had a significantly higher waste rate than the other varieties analyzed ($P < 0.05$), and its yield factor after peeling was low compared to the other three (0.51 ± 0.02), representing 51% of the edible portion. Its yield coefficient was also significantly higher than the other varieties (1.95). For the two taro varieties, the parameters studied were statistically different.

3.2. Water Absorption and Yield Factor of Tubers, Roots and Bananas after Cooking

The water absorption (WA) rate, yield factor, and yield coefficient after cooking (CT) of tubers, roots, and bananas are presented in Table 2. The result revealed that the Bisamunyu banana had a high-water absorption rate and YF ($P < 0.05$)

than other banana varieties; cassava, taro (*Manyango*), and *French* plantain absorb almost the same amount of water during boiling. Fried cassava exhibited a particular characteristic since frying causes significant water loss during cooking.

Table 1. Edible coefficient, yield coefficient and yield factor.

Food items	% EC	YC	YF
	$\bar{x} \pm SD$	$\bar{x} \pm SD$	$\bar{x} \pm SD$
Fresh Sweet Cassava	17.25 ± 0.71^{DE}	1.21 ± 0.09^{D}	0.83 ± 0.005^{A}
Yellow-flesh Sweet Potato (YSP)	19.25 ± 2.38^{D}	1.28 ± 0.05^{CD}	0.79 ± 0.03^{BC}
White-Flesh Sweet Potato (WSP)	19.85 ± 1.86^{D}	1.25 ± 0.03^{D}	0.80 ± 0.02^{AB}
Taro (*Colocasia esculenta*)	15.42 ± 2.02^{E}	1.22 ± 0.05^{D}	0.82 ± 0.03^{AB}
Taro (*Xanthosoma esculenta*)	26.09 ± 0.81^{C}	1.35 ± 0.01^{C}	0.74 ± 0.00^{C}
Faux-corne Plantain	44.23 ± 1.05^{B}	1.79 ± 0.03^{B}	0.56 ± 0.01^{D}
French Plantain	48.68 ± 1.90^{A}	1.95 ± 0.07^{A}	0.51 ± 0.02^{E}
Dessert Banana	44.59 ± 1.15^{B}	1.81 ± 0.04^{B}	0.55 ± 0.01^{D}
Bisamunyu Banana	45.75 ± 2.08^{AB}	1.85 ± 0.07^{B}	0.54 ± 0.02^{DE}

The mean represented with different letters in the same column are significantly different from each other ($P < 0.05$). EC = edible coefficient, YC = yield coefficient, YF = yield factor. YSP: yellow sweet potato, WSP: white sweet potato.

Table 2. Cooking time (CT), water absorption, yield factor, and yield coefficient after cooking.

Food items	CT	WA (%)	YF	YC
	(minute)	$\bar{x} \pm SD$	$\bar{x} \pm SD$	$\bar{x} \pm SD$
Fresh Sweet Cassava	35	10.40 ± 1.9^{BC}	1.12 ± 0.02^{BC}	0.90 ± 0.02^{CD}
Fried Cassava (molecule)	15	nd	0.78 ± 0.1^{E}	1.28 ± 0.05^{A}
Yellow-Flesh sweet potato	33	4.34 ± 0.87^{D}	1.04 ± 0.02^{D}	0.96 ± 0.0^{B}
White-Flesh sweet potato	33	4.86 ± 1.01^{D}	1.05 ± 0.01^{D}	0.95 ± 0.01^{B}
Taro Manyango	45	9.94 ± 1.60^{BC}	1.11 ± 0.02^{BC}	0.90 ± 0.016^{CD}
Taro (*Xanthosoma*) Maole	30	3.57 ± 0.79^{D}	1.04 ± 0.012^{D}	0.96 ± 0.03^{B}
Faux-corne Plantain	30	9.62 ± 1.81^{C}	1.10 ± 0.02^{C}	0.90 ± 0.02^{CD}
French Plantain	30	11.31 ± 1.14^{BC}	1.13 ± 0.01^{BC}	0.89 ± 0.00^{D}
Dessert Banana	20	12.21 ± 0.25^{B}	1.14 ± 0.03^{B}	0.88 ± 0.00^{D}
Bisamunyu Banana	19	20.34 ± 0.57^{A}	1.25 ± 0.01^{A}	0.80 ± 0.002^{E}
X ± SD	29 ± 8.39	9.621 ± 5.15	1.11 ± 0.11	0.904 ± 0.12

The mean ± SD with different superscript letters in the same column are significantly different from each other ($P < 0.05$). SD = standard deviation, CT = cooking time in minutes, nd = not determined, WA = water absorption.

3.3. Yield after Cooking of Rice and Paste (*foufou*)

The water absorption rate, sample weight before and after cooking, cooking time and quantity of water used, yield and coefficient of return after cooking of rice and paste of corn flour and cassava (*foufou*) are presented in Table 3.

Table 3. Physical parameters related to cooking and yield of rice and paste.

Food items	Weight (g)		H_2O (mL)	CT (min)	WA (%)	YF	YC
Rice	Before	After					
Bamanga-White rice	500	1125	1110	29	55.55	2.25	0.44
Opala-Brown rice	500	1307	1250	43	61.74	2.61	0.38
Bumba-White rice	500	1167	1060	29	57.16	2.33	0.43
Holland imported rice	500	1508	1110	35	66.84	3.016	0.33
Yanfira-White rice	500	1414	1150	40	64.64	2.828	0.35
$\bar{x} \pm$ SD	500 ± 0	1304.2 ± 144.6	1136 ± 63.7	35.2 ± 5.7	61.19 ± 4.3	2.60 ± 0.28	0.38 ± 0.04
Flour (cassava-maize-semolina)							
Cassava flour	250	692	640	9	63.87	2.76	0.36
Corn flour	250	833	810	21	69.98	3.33	0.30
Mix of corn flour and cassava	250	714	900	12	64.98	2.85	0.35
Semolina	250	741	870	17	66.26	2.96	0.34
Mix semolina and cassava	250	661	810	11	62.18	2.64	0.38
$\bar{x} \pm$ SD	250 ± 00	728.2 ± 58.60	806 ± 90.02	14 ± 4.38	65.454 ± 2.63	2.90 ± 0.23	0.346 ± 0.026

$\bar{x} \pm$ SD = mean ± standard deviation, CT = cooking time in minutes, YF = yield factor, YC = yield coefficient, WA: water absorption.

The Holland imported rice had a high yield factor, followed by rice from Yafira. Regarding the paste (fufu), the corn flour hydrated more than the other flours, followed by semolina. The average amount of cooking water was 1136 ± 27.57 mL for rice and 806 mL ± 27.56 mL for paste.

3.4. Physical Parameters of Three Food Groups

Figure 1 presents the hydration rate, the YF, and the YC for the three food groups cooked by boiling.

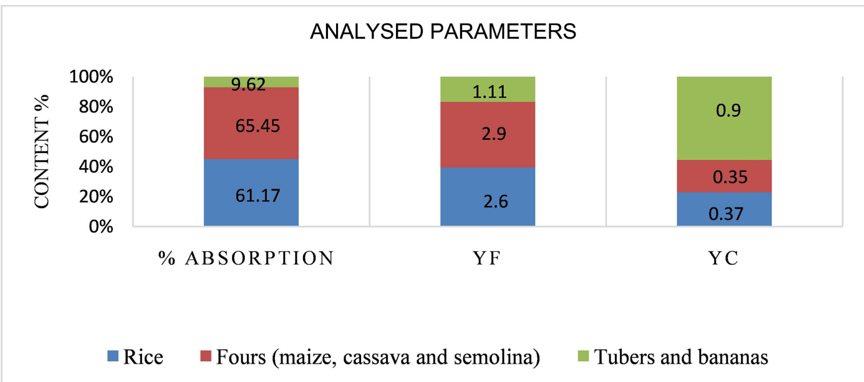

Figure 1. Physical parameters according to the three food groups.

The hydration rates and yield coefficients of cereals (rice) and flour paste (cassava, corn, and semolina) are significantly higher than those of tubers. However, tubers have a higher YC as compared to flours and rice.

3.5. Average Chemical Composition of Three Food Groups

The proximate chemical compositions of three food groups after cooking were presented in Table 4.

Table 4. Average proximate composition of three food groups (g/100g).

Food Group	Moisture $\bar{x} \pm SD$	Ash $\bar{x} \pm SD$	Protein $\bar{x} \pm SD$	Lipid $\bar{x} \pm SD$	Fibre $\bar{x} \pm SD$	CHO $\bar{x} \pm SD$	Kcal/100g $\bar{x} \pm SD$
Cereal (rice)	67.12 ± 1.39^{A}	0.38 ± 0.07^{B}	2.84 ± 0.3^{A}	0.29 ± 0.05^{B}	0.65 ± 0.36^{B}	28.68 ± 1.59^{A}	128.78 ± 5.80^{A}
Flour (cassava, corn, and semolina)	66.60 ± 1.28^{A}	0.41 ± 0.05^{B}	2.0 ± 0.64^{B}	0.58 ± 0.18^{A}	0.62 ± 0.34^{B}	29.76 ± 2.12^{A}	132.35 ± 5.57^{A}
Tuber/banana	64.81 ± 6.64^{A}	0.82 ± 0.22^{A}	1.18 ± 0.43^{C}	0.31 ± 0.22^{B}	1.60 ± 0.59^{A}	31.30 ± 6.48^{A}	132.7 ± 26.6^{A}

The mean ± SD with different superscript letters in the same column are significantly different ($P < 0.05$). CHO-carbohydrate.

The result showed that only the protein content differs significantly in these three food groups after cooking ($P < 0.05$). The tubers exhibited a high crude fiber and ash content, while the flours had high lipid content.

The approximate chemical composition of each food analyzed is presented in Table 5.

Table 5. Proximate chemical composition of the samples (g/100g).

Foods items	Moisture	Ash	Protein.	fat	Fiber	CHO	Energy (Kcal)
Boiled fresh cassava (Manihot esculenta)	64.4 ± 0.87^{GH}	1.07 ± 0.14^{A}	1.17 ± 0.08^{GHI}	$0.30 \pm 0.10^{E-H}$	1.38 ± 0.88^{EFG}	31.66 ± 0.73^{EFG}	$134.10 \pm 4.72^{D-G}$
Fried cassava	55.27 ± 1.14^{JK}	1.10 ± 0.26^{A}	1.8 ± 0.05^{DE}	1.05 ± 0.06^{A}	$1.76 \pm 1.04^{B-E}$	39.02 ± 2.00^{BC}	172.73 ± 8.33^{A}
Grated cassava (masele)	77.21 ± 3.86^{A}	$0.67 \pm 0.08^{B-E}$	0.26 ± 0.01^{K}	0.12 ± 0.08^{H}	0.37 ± 0.19^{IJ}	21.36 ± 3.76^{M}	87.69 ± 12.54^{L}
Chikwangue *Bingwele*	57.53 ± 0.30^{IJ}	$0.64 \pm 0.09^{B-F}$	0.51 ± 0.04^{Jk}	0.19 ± 0.09^{FGH}	0.73 ± 0.09^{HIJ}	40.4 ± 0.33^{AB}	164.35 ± 1.91^{AB}
Chikwangue *Topoke*	53.33 ± 3.42^{K}	1.03 ± 0.05^{A}	0.80 ± 0.08^{IJ}	0.22 ± 0.07^{FGH}	1.55 ± 0.45^{DEF}	43.07 ± 3.12^{A}	177.48 ± 11.26^{A}
Plantain banana (*faux-corne*)	63.6 ± 0.4^{H}	1.10 ± 0.6^{A}	1.18 ± 0.03^{GHI}	$0.32 \pm 0.12^{E-H}$	$1.19 \pm 0.11^{E-H}$	32.60 ± 0.62^{DE}	138.03 ± 1.85^{CD}
Plantain banana (*French*)	59.4 ± 0.2^{I}	1.13 ± 0.09^{A}	1.24 ± 0.04^{GH}	$0.31 \pm 0.10^{E-H}$	1.69 ± 0.36^{CDE}	36.22 ± 0.44^{CD}	152.60 ± 2.55^{BC}
Bisamunyu banana	64.3 ± 4.97^{GH}	0.73 ± 0.20^{CB}	1.44 ± 0.40^{EFG}	$0.28 \pm 0.11^{E-H}$	1.53 ± 0.18^{DEF}	31.72 ± 4.47^{EFG}	135.17 ± 18.93^{DEF}
Dessert banana	69.63 ± 3.65^{BCD}	0.78 ± 0.03^{B}	1.03 ± 0.14^{HI}	0.25 ± 0.04^{FGH}	1.49 ± 0.18^{DEF}	$26.8 \pm 3.41^{H-L}$	113.58 ± 14.12^{IJK}
Colocasia esculenta (*taro Manyango*)	71.06 ± 3.60^{B}	$0.64 \pm 0.09^{B-F}$	1.76 ± 0.12^{DEF}	0.14 ± 0.08^{GH}	2.3 ± 0.04^{ABC}	24.1 ± 1.59^{LM}	104.64 ± 5.88^{K}
Xanthosoma (*taro Maole*)	70.63 ± 1.09^{BC}	0.42 ± 0.15^{FC}	$1.42 \pm 0.11^{E-H}$	0.17 ± 0.08^{GH}	$2.09 \pm 0.08^{A-D}$	25.26 ± 1.19^{KL}	108.27 ± 4.39^{JK}
White-fleshed sweet potato	$68.53 \pm 4.16^{B-F}$	0.70 ± 0.21^{BCD}	1.44 ± 0.22^{EFG}	0.39 ± 0.09^{DEF}	2.45 ± 0.34^{A}	$26.47 \pm 4.26^{I-L}$	$115.21 \pm 15.86^{H-K}$
Yellow-fleshed sweet potato	$67.72 \pm 1.36^{B-G}$	0.75 ± 0.15^{B}	1.37 ± 0.17^{FGH}	$0.31 \pm 0.04^{E-H}$	2.35 ± 0.29^{AB}	$28.3 \pm 0.69^{G-K}$	$121.53 \pm 3.57^{F-J}$
Rice from Bamanga	$65.66 \pm 0.83^{E-H}$	0.31 ± 0.16^{G}	2.78 ± 0.05^{BC}	0.21 ± 0.19^{FGH}	0.4 ± 0.24^{IJ}	30.6 ± 0.81^{EFG}	135.57 ± 3.32^{DEF}
Rice from Opala	$66.46 \pm 0.71^{D-H}$	$0.5 \pm 0.08^{C-G}$	3.42 ± 0.12^{A}	0.35 ± 0.27^{EFG}	$1.2 \pm 0.05^{E-H}$	$28.04 \pm 0.94^{G-K}$	$129.02 \pm 5.90^{D-I}$

Continued

Rice from Bumba	66.06 ± 0.23^{D-H}	0.45 ± 0.05^{EFG}	2.58 ± 0.16^{BC}	0.32 ± 0.16^{E-H}	0.5 ± 0.09^{IJ}	30.08 ± 0.13^{E-I}	133.48 ± 1.73^{D-G}
Rice from Yafira	69.40 ± 2.44^{B-E}	0.31 ± 0.10^{G}	2.89 ± 0.63^{B}	0.33 ± 0.09^{E-H}	0.95 ± 0.26^{F-I}	26.10 ± 2.23^{JKL}	118.95 ± 9.80^{G-K}
Imported holland rice	68.03 ± 2.46^{B-G}	0.35 ± 0.03^{G}	2.53 ± 0.25^{BC}	0.26 ± 0.07^{FGH}	0.23 ± 0.11^{J}	28.6 ± 2.20^{F-K}	126.86 ± 10.21^{D-I}
Cassava flour paste (*foufou*)	66.86 ± 3.35^{C-H}	0.43 ± 0.02^{FG}	1.27 ± 0.06^{GH}	0.29 ± 0.15^{E-H}	0.33 ± 0.14^{IJ}	30.79 ± 3.78^{EFG}	130.93 ± 13.36^{D-G}
Mix cassava + corn flour paste	65.2 ± 2.94^{FGH}	0.46 ± 0.10^{EFG}	2.47 ± 0.12^{C}	0.59 ± 0.13^{CD}	0.85 ± 0.11^{G-J}	30.40 ± 3.03^{E-H}	136.91 ± 10.86^{DE}
Corn flour paste	68.73 ± 1.33^{B-F}	0.47 ± 0.15^{D-G}	2.91 ± 0.12^{B}	0.83 ± 0.13^{B}	1.2 ± 0.03^{E-H}	25.84 ± 1.25^{KL}	122.47 ± 5.63^{E-J}
semolina flour paste	66.88 ± 1.03^{C-H}	0.31 ± 0.03^{G}	2.05 ± 0.68^{D}	0.71 ± 0.12^{BC}	0.38 ± 0.06^{IJ}	29.65 ± 1.88^{E-J}	133.26 ± 4.28^{D-G}
Mix semolina and cassava flour paste	65.33 ± 0.75^{FGH}	0.38 ± 0.03^{G}	1.31 ± 0.02^{GH}	0.49 ± 0.09^{DE}	0.34 ± 0.07^{IJ}	32.14 ± 0.75^{EF}	138.20 ± 3.65^{CD}

The mean ± SD with different superscript letters in the same column are significantly different from each other (P < 0.05). Means that were followed by more than 3 superscript letters were separated by a hyphen, for example, 122.47 Kcal ± 5.63 EFGHIJ, is written as 122.47 Kcal ± 5.63E–J, *i.e.*, all alphabetical letters between these two letters are included.

Grated cassava (masele) showed significantly higher moisture content (77.21 ± 3.86) P < 0.05 as compared to other sample, followed by sweet potato, taro, and table banana. Brown rice from Opala exhibited high protein (3.42 ± 0.12 g/100g) and crude fiber (1.2 ± 0.05 g) content than the rest of rice samples whereas chikwangue *Topoke* had high carbohydrate (43.07 g/100g) and energy (177.48 Kcal/100g) content.

4. Discussion

4.1. Waste Rate and Yield Factor of Tubers and Bananas

This study finding revealed that the French plantain variety exhibited a significantly higher waste rate than the other analyzed varieties (48.68 g ± 1.9 g), followed by the Bisamunyu banana with 45.75 g ± 2.08 g (P < 0.05). However, the yield of French plantain after peeling was low (0.51 ± 0.02), or 51 % of the edible portion (**Table 1**). Previous studies reported the yield factors for the Cavendish French plantain: 0.50, or 50% of the edible portion as reported by Vincent; 0.57, or 57% [19]; and 0.62, or 62 % of the edible portion [20]. In general, for a mature banana, the skin represents 35% to 40% of gross weight [21]. Nevertheless, this weight depends on the age of the fruit and agricultural practices (fertilization, irrigation). It should be remembered that the peel initially weighs five times more than the pulp, the latter developing during ripening [22].

Sweet cassava had a waste rate of 17.25% almost similar to the 16% cassava waste rate described in the FAO/INFOOD table [19]; but lower than the 26% waste rate described in the Burkinabé table [23]. This waste rate result (17.25%) for cassava was not statistically different from the waste rate of yellow-fleshed sweet potato (19.25%) and *Colocasia esculenta* (15.42%). The 18% waste rate and 82% edible part were reported in the sweet potato variety Lira [24]. The differences observed for the waste rate could be due to the variety of food crops and its maturity. The yield factor varied significantly among foods, being very low in *French* plantain and Bisamunyu banana with values of 0.51 ± 0.02 and 0.54 ± 0.02 respectively ($P < 0.05$). The sweet cassava and Colocasia esculenta were exhibited high yield factor, 0.83 ± 0.01 and 0.82 ± 0.03 respectively (**Table 1**), as compared to others. The FAO/INFOOD composition table stated that the yield factor of 0.84 for cassava, 0.52 for banana, 0.79 for yellow sweet potato, 0.83 for white sweet potato, 0.86 for taro and 0.50 for unripe dessert banana. Yield factors and its coefficient are used to denote the weight of a food or dish retained after preparation, processing or other treatment, compared to the absolute weight of the food before preparation [25]. The YF and YC are often used in the estimation of actual weight of dishes that must be prepared for a sick person for food containing waste. The YF allows determining the actual quantity of tuber after peeling. E.g. for 1 kg of yellow-fleshed sweet potato, the edible part content is calculated by multiplying (1000 g × 0.79 = 790 g) and the YC would allow to determine the quantity of tuber to buy at the market. Example to prepare 200 g of edible part of *faux-corne* plantain banana, it is necessary to multiply 200 g × 1.79 which is the YC which gives 358 g to buy at the market.

4.2. Water Absorption and Yield after Cooking of Tubers and Bananas

Table 2 presents the water absorption and yield after cooking of tubers and bananas. The statistical analysis showed that the Bisamunyu banana had a water absorption rate of 20.34% and a yield factor of 1.25 ± 0.01 which is higher than the other banana types and tuber varieties ($P < 0.05$). This is probably due to the cell matrix of this variety, which is not resistant and absorbs a lot of water; cassava, *Colocasia esculenta*, and *French* plantain did not show a significant difference in the amount of water absorbed. However, the *Xanthosoma* taro (Maole) had a water absorption (WA) rate of 3.57% ± 0.7% lower than the *Colocasia esculenta* (taro Manyango) (9.94% ± 1.60%) and the other tubers analyzed ($P < 0.05$). Agbaeze *et al.*, [26] found that sweet cassava variety TMS 419 had a water absorption rate of 2.59% which was much lower than the findings (10.40%) of this study. According to Kouadio *et al.*, (2011), the WA rate of 9.5% ± 2.9% and 3.9% ± 0.73% were reported in floury culinary grade and hard culinary yam grade respectively whereas the WA rate of 27.6% and 12.4% respectively for floury grade and hard cassava grade cassava [14]. The WA rates ranging from 5% to 20% after 30 minutes of boiling of cassava have been reported [27]. Fried cassava had a yield factor of 0.78 ± 0.1 and yield coefficient of 1.28 ± 0.05 which suggests that cassava samples lost water after frying. The YF of 1.14 in purple-skinned sweet potato and 1.17 in boiled cassava were reported [6] [28], which was higher than 1.05 found in white-fleshed sweet potato. The water absorption would be explained by the fact that during cooking, starch gelatinizes and granules swell by absorbing water. The extent of tuber water absorption varies according to genotype [27] but also amylopectin content as it is more involved in starch grain swelling [29].

The average cooking time for all roots was 30.55 minutes (**Table 2**). This is consistent with the sweet potato cooking time of 30 - 45 minutes reported by Dincer *et al.* [30] but different from the 42.4 to 52.6 minutes reported by Mwanga [24]. The boiling time of roots and legumes like beans depends on genetic and environmental factors, maturity and post-harvest storage time [31] [32]. For example, before 6 months of age, the accumulation of starch in the tuber is incomplete, allowing for rapid cooking; however, if stored for a long time after harvest, the tuber becomes dry and takes time to cook [33].

4.3. Physical Parameters Related to Cooking and Yield of Rice and Pasta

The imported Holland rice and Yafira rice had a hydration rate of 66.84 and 64.64% respectively, probably due to their high-water absorption capacity. The average volume of cooking water for 500 g of rice was 1136 ml (ranging from 1060 for *Bumba*-White rice to 1250 mL for *Opala*-Brown rice) and 806 ml for cooking 250 g of flour (ranging from 640 mL for cassava flour to 900 mL for mix corn-cassava flour (**Table 3**). Agbaeze *et al.* [26] reported a YF of 2.76 in their study which corroborates our result for cassava flour paste. The cooking time of different rice samples was 35.2 ± 3.04 min which was different from 23 min found for steamed rice [34]. However, cooking time of 45 - 56 min for parboiled rice and 49 min for unparboiled rice has also been reported [35].

In this study, the rice YF varied between 2.25 for Bamanga rice and 3.03 for imported Holland rice with an average of 2.60 ± 09 for the five samples, which is consistent with the average swelling ratio of 2.77 and 2.98 reported in other studies [6] [34]. Variation in cooking time and water absorption capacity of rice depends on the cohesion between endosperm cells which causes the tightly packed starch granules to hydrate more slowly, resulting in decreased water penetration into the grain [35].

The water absorption rate was on average 61.17% and 65.45% respectively for the rice and flour group which was significantly higher than 9.62% observed in the tuber and bananas $P < 0.05$ (**Figure 1**). This is could be due to the fact that fresh tubers are rich in water and that during cooking the starch hydrates from this endogenous water limiting the absorption of large quantities of cooking water, on the other hand, rice and flours are very low in water before cooking which promotes sufficient absorption of large quantities of water during cooking [35].

4.4. Chemical Composition of Three Food Groups

The moisture, carbohydrate, and energy levels in the cereal, flour, and tuber samples were not statistically different after cooking ($P > 0.05$). However, the protein content was significantly higher for rice (2.84 ± 0.31) and flour (2.000 ± 0.64) compared to 1.18 ± 0.43 observed in the tuber ($P < 0.05$) (**Table 4**). Protein plays many roles in the human body; however, it must be at good biological value. Cereal proteins are deficient in lysine, an essential amino acid found in large quantities in legumes, hence the importance of their association in the meal [36]. Crude fiber and ash are higher in tubers than in cereals and flours ($P < 0.05$); we believe that the processing grains and flour before cooking causes them to lose a considerable amount of crude fiber and minerals, unlike tubers which are just peeled and cooked immediately. Dietary fiber is important for health state, it increases satiety and delay the time for carbohydrates from a food to be absorbed into the intestine [37].

4.5. Proximate Chemical Composition

Regarding the chemical composition of individual foods after cooking, low moisture levels were observed in *Topoke* chikwangue and fried cassava, with 53.33% ± 3.42% and 55.27% ± 1.14%, respectively, and the highest level was observed in grated cassava (77.21% ± 3.82%) (**Table 5**). These results may be attributed to the preparation and cooking method of *Topoke* chikwangue (pounding and shaping). Fried cassava loses water during frying. Deep frying and air frying, both drying cooking methods, have been shown to lead to loss of moisture and other volatile substances [38]. The moisture content of 64.4% observed in boiled cassava was in the range of 62.1% and 72.1% reported in boiled cassava in another study [14], the moisture content of white sweet potato (68.53% ± 4.16%) was in the range of 50.23 to 83% reported in white and orange flesh sweet potato according to different cooking methods (grilling, frying and boiling) [28] [30] [38] [39].

The moisture content found in taro (71.06% ± 3.6%) corroborated with 73% reported in taro after boiling in another study [40]. Boiled *French* plantain had a moisture content of 59.4% ± 0.2% which was consistent with 59.0% reported in the FAO table [41]. Moisture content of a food plays an important role in digestion, it allows for good chewing, and influences swallowing, the efficiency of digestive enzymes and intestinal health. High moisture content of a food has an impact on its shelf life and storability [39].

Ash content was significantly low in Semolina (0.31% ± 0.03%), in the rice from *Yafira* and (0.31% ± 0.10%) *and Bamanga* (0.31% ± 0.16%) and was statistically high in *French* plantain (1.13% ± 0.09%), *faux-corne* banana (1.10% ± 0.6%) and fried cassava (1.10% ± 0.26%) (**Table 5**). Ash content of 0.2% in boiled rice, 0.5% in cassava paste (*foufou*), 0.9% in boiled cassava and 0.9% in sweet potato were reported in FAO/INFOOD table. However, high ash values of 0.5% in maize paste, 1.3% in cassava paste (*foufou*), 1.2% in boiled taro, 1.2% in boiled sweet potato and 1% in boiled cassava were reported in the Kenyan food composition table. The ash content indicates the mineral composition of the food sample [42]. The low ash value observed in rice could be due to the loss of minerals in the cooking water. It was also reported an increase in ash content in yellow yam from 0.63% fresh to 1.43% after roasting, while a decrease in ash was observed in plantain from 3.31% fresh to 3.14% after boiling [43].

The lowest protein contents were observed in grated cassava (0.26% ± 0.01%) and chikwangue Bingwele (0.51% ± 0.04%). Protein content was significantly higher in rice from Opala (3.42 ± 0.01) ($P < 0.05$) (**Table 5**). Taro had a protein content of 1.76% ± 0.12% higher than that of boiled cassava (1.17% ± 0.08%) and sweet potato (1.44% ± 0.22%). Protein content of 1.76% and 1.8% were reported in taro in other studies [40] [44]. Our result about protein content in boiled cassava (1.17%) was in line with Alamu *at al.* [45] who also found 1.17% of protein. Cooking method influences nutrient content in foods. Sulaiman *et al.* [39] observed an increase in protein content from 2.99% to 3.99% after roasting orange-fleshed sweet potato and a decrease in boiled samples (2.99% to 2.28%), a variation that could be attributed to the dispersion of nitrogenous compound in the cooking medium [46]. Also, other authors reported protein content of 2% in cassava flour [47], 1.03% and 1.89% in fresh plantain [48] [49] and 0.91% in boiled plantain [49].

Generally, the analyzed foods were low in lipids with significantly low levels were observed in grated cassava (0.12% ± 0.08%), *Colocasia esculenta* (0.14% ± 0.08%) and chikwangue Bingwele (0.19% ± 0.09%). Busch *et al.* [40] reported that a lipid content of 0.3% in dry matter of taro after boiling. However, high lipid level was observed in fried cassava (1.05% ± 0.06%) $P < 0.05$ (**Table 5**). Lipid contents of 0.26%, 2.5%, and 0.9% were reported in fresh, fried and roasted orange sweet potato respectively [39]. The high fat content in fried cassava may be due to the absorption of oil from the sample during the frying process onto the food after water is partially lost [46].

White-fleshed sweet potato and taro tubers exhibited significantly higher crude fiber content (2.45% ± 0.34% and 2.3% ± 0.04%), respectively as compared to other foods. The lowest values were observed for imported Holland rice 0.23% ± 0.11%, grated cassava 0.37% ± 0.19% ($P < 0.05$) this fiber content of sweet potato is much higher than the value of 0.45% - 1.5% reported by [39] in storm-fleshed sweet potato. However, the crude fiber content found in boiled plantain (1.69% ± 0.36%) was lower than 1.80% - 2.27% reported in roasted plantain [50]. Fiber contents of 2.75% and 3.8% were also reported in green plantain and corn *foufou* respectively [20]. Dietary fiber contributes to satiety after consumption and lowers the glycemic index of a food [37].

Carbohydrate content was significantly high in *chikwangue Topoke* (43.0% ± 3.12%) and *Bingwele* (40.4% ± 0.33%) and was low in grated cassava (21.36% ± 3.76%), corn pasta (25.84% ± 1.25%) and white-fleshed sweet potato (26.47 ± 4.26) (**Table 5**). Carbohydrate contents of 15.25%; 40.75% and 30.55% were reported in boiled, roasted and fried sweet potatoes respectively [39]. The carbohydrate content in taro found in this study (24.1 ± 1.59) was lower than 28.8% and 32% reported by other studies [51]. Besides, the FAO/Kenya table reported a carbohydrate content of 20.1% in green plantain, 33.4% in cassava and 26.0% in maize *Ugali* which was similar to our results. The carbohydrate content of 72.9% and 70.3% was observed in raw brown rice and white rice but after boiling the content of 29.1% and 26.4% were respectively observed [41].

The energy value was significantly high in *chikwangue Topoke* and fried cassava with 177.48 Kcal ± 11.26 and 172.73 Kcal ± 8.33 respectively and the lowest was in grated cassava (87.69 ± 12.54) $P < 0.05$ (**Table 5**). We believe that the cooking processes of fried cassava and the preparation of chikwangue decrease the water content and increase the proportion of dry matter. Because, the water content significantly influences its energy value and the nutrient content of the food. Stewart *et al.* [52] reported 77 Kcal in boiled sweet potato and 164 Kcal/100g in fried sweet potato an increase which could be due to the decrease in moisture and fat absorption [52]. The Kenyan food composition table reports 119 Kcal/100 in boiled rice, 141 Kcal in maize *ugali*, 186 Kcal in cassava *ugali* flour. The FAO/INFOOD table reports 130 Kcal in thick yellow maize flour porridge, 138 Kcal in boiled drained brown rice, 118 Kcal in boiled polished white rice which was in the range of the content energy found in foods analyzed in this study [41].

5. Conclusion

The results of this study truly indicate the changes made during food processing before cooking; different ECs were observed in tubers and bananas. The variation in YF and YC indicates that special attention must be paid when preparing a dish, because considering the weight and chemical composition of a raw food in dietary prescriptions overestimates or underestimates the amount of nutrients provided. The retention factor, which indicates the amount of nutrients retained after cooking, and the yield factor, which indicates the change in food weight due to either the absorption or loss of water or oil, are crucial for better dietary prescriptions. This study provides data on the approximate chemical composition of a large portion of the foods consumed in Kisangani. Healthcare providers should therefore use this information to improve dietary prescriptions for patients.

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Conflicts of Interest

The authors declare no conflict of interest.

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