Original Research Article

Search for local food supplements: Study of the nutritional value of 15 plant species from Niger.

ABSTRACT

In Niger, the prevalence of malnutrition and mortality linked to undernutrition among Nigerien children under 5 years of age remains high and constitutes a major concern for public authorities. However, the country is teeming with significant biodiversity that could help combat high levels of undernutrition among children aged 6 to 59 months. The present study aimed to evaluate the nutritional quality of 15 plant species of which 17 samples were taken as potential complementary foods. The water, ash, lipids, protein and cellulose content were determined. Carbohydrate content and energy density were calculated. Biochemical characterization of the sampled foods showed that *Glycine max seeds* were richer in protein(36.39%). *Neocarya macrophylla* almond has a relatively high lipid content (60.75%) and cellulose content (26.74%). The pulp of *Hyphaenethebaica*wasrich in mineral elements (7.16%). The tuber of *Ipomoea batatas* (95.25%) and the pulp of *Neocarya macrophylla* (93.01%) contained sufficient carbohydrates, and the humidity was found to be higher specifically in the cereal (Pennisetum*glaucum)* and the tuber of *Borassus aethiopum* with rates of 6.72% and 5.70 %, respectively. In addition, a positive and significant correlation was observed on the one hand between the cellulose content and that of proteins and lipids and between the protein and lipid levels. In contrast, the correlation between carbohydratelevels and those of proteins and lipids was negative and very significant. The results confirm that pulps and kernels of fruits, legumes, tubers, and cereals can be incorporated into numerous preparations intended for children to supplement their diet.

Keywords: *Local food products, Nutrition, Food supplement, Niger*

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1. INTRODUCTION

In the Sahel, drought is the main risk affecting agrosylvopastoral production through reductions in food production, in the number of animals and their productivity, andin agricultural income, with the consequence of food insecurity, food crises, and nutrition[1]. Indeed, in developing countries, intake is -

more monotonous in their composition, with diets lacking diversity. The degree of economic development and income level have important implications for the types of food that can be produced to satisfy human needs [2] . Thus, food prices and a country's economy are factors that influence human nutrition [3] . The Sahel is characterized by a high prevalence of malnutrition and mortality linked to undernourishment among children under 5 years of age. The causes of malnutrition are multiple factors. This can result from inadequate food intake, diseases, household food insecurity, access to health services, inappropriate care practices, access to drinking water, andpoor living conditions. hygiene [4] .

In Niger, malnutrition, particularly undernutrition and micronutrient deficiencies, persists and constitutes a public health problem [5] . Thus, the prevalence of global acute malnutrition (GAM) among children aged 6 to 59 months, severe acute malnutrition, and chronic malnutrition (stunting) is estimated at 12.2% (well above above the WHO safety threshold of 10%), 2.4% and 47.0% [6] . Factors associated with chronic malnutrition are age, sex, birth order, mothers' educational level, diarrhea, fever, acute respiratory infection, and anemia [7].

In addition, on a practical level, complementary feeding was introduced in a timely manner in 8 out of ten cases (80.6%), but less than half of the children (47%) received breast milk until the age oftwo years. The diet of children aged 6to23 months was generally poorly diversified (the minimum dietary diversity rate was 8.7%), mainly based on starchy foods (91.1%), followed by legumes and nuts (29.6%), fruits and vegetables rich in vitamin A (25.6%), and breast milk (85.6%). Therefore, the prevalence of overall anemia (mild, moderate and severe) in children aged 6 to 59 months is high (55.5% [6] .

The issue of nutrition is seen today as a global concern, characterized by a real collective awareness expressed within the Scaling Up Nutrition (SUN) Movement, which brought together 60 countries in 2017 [4]. One of the most promising solutions to combat malnutrition sustainably is to design programs that consider locally produced foods [8]. Dietary approaches constitute levels that can significantly contribute to reducing the prevalence of malnutrition [9]. For example, daily supplementation with moringa leaf powder significantly improves the nutritional status of children in terms of wasting, stunted growth, and underweight [9].

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From the age of six months, breast milk intake is insufficient to meet the needs of infants and young children and must be supplemented by a diversified and high nutritional density so-called “complementary” diet [10]. The present studyaimed to evaluate the nutritional quality of 15 plant species, from which 17 samples were collected as potential complementary foods.

2. MATERIALS AND METHODS

2.1. Presentation of the study area

The urban commune of Niamey (Niger) served as the study site. It comprises five (5) municipal districts(Figure 1). The population of Niamey is estimated to be approximately 1,492,414 inhabitants [11] . The average rainfall and temperature were 539.16 mm and 29.59°C, respectively [12]. In addition, a previous study listed 15 types of porridge used as complementary food among children aged 6 to 24 months in the urban community of Niamey, six of which come from industrial flours of known composition and the other nine are porridges. Local traditions [13]. In this region, the continuation of breastfeeding until the age of two years was estimated at 14.9%, and the minimum dietary diversity among children aged 6 – 23 months was estimated to be 31.1% [6].

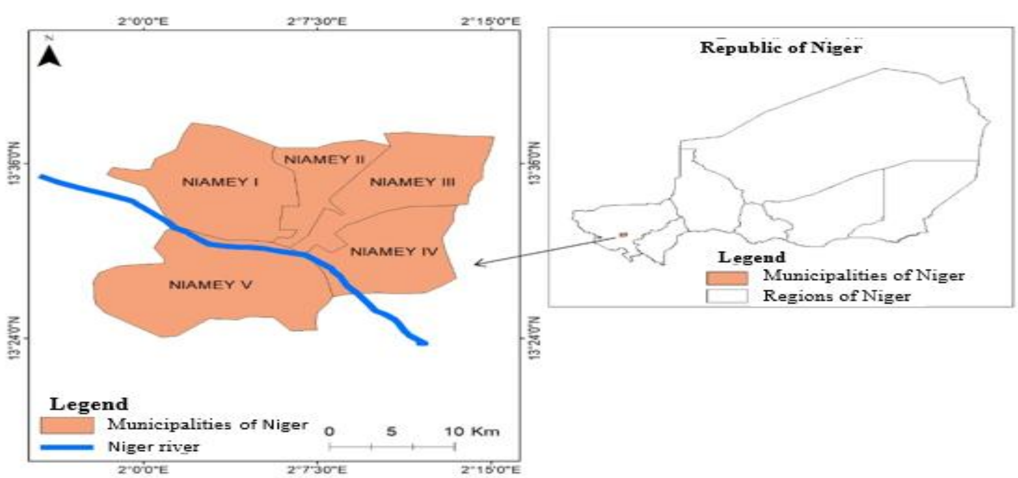

Figure1: Map of the study area.

2.2 . Plant material

It was made up of 15 plant species, from which 17 samples were collected. The scientific names of the plant species, organs used, vernacular names, and provenances are listed in Table 1. This tableshows that six samples were used in the grilled form, eight in the raw form, and three in the cooked form.

Table 1: Composition and characteristics of plant material

Scientific names	Names in French	Local names	Languages [1]	Organs used [2]	Codes	Forms used	Origins
Adansonia digitata	Baobab	kuka, koo nya, bokki,	H, Z, F	Pu	Addi	believed	Local market
Arachis hypogaea	Peanut	gujiya, damsi, kolhi,	H, Z, F	Gr	Arhy	grilled	Local market
Glycine max	Soy		H, Z, F	Gr	Glma	grid	Local market
Ziziphus mauritiana	Jujube	magaria, darey, djâbhi,	H, Z, F	Am	ZimaA	believed	Local market
Western Anacarduim	Cashew	Say tourizé	Z	Am	Anoc	grid	Local market
Borassus aethiopum	Rônier	jijinia, bê, dubbhy	H, Z, F	Tu	Boae	cooked	Local market
Parkia biglobosa	Nere	dorowa, dosso, nareehi,	H, Z, F	Pu	Pabi	believed	Local market
Cucurbita SP.	Squash	kankana, laptanda, faireare.	H, Z, F	Gr	Cusp	believed	Local market
vigna unguiculata	Cowpea	wake, dunguri, yanpu,	H, Z, F	Gr	Viun	cooked	Local market
Neocarya macrophylla	cayor apple tree	gawasa, gamsa, nawudi,	H, Z, F	Pu	NemaF	believed	Local market
Neocarya macrophylla	cayor apple tree	gawasa, gamsa, nawudi,	H, Z, F	Am	NemaA	believed	Local market
Sesamum indicum	Sesame	lamti, lamti,	H, Z, F	Gr	Breast	grid	Local market

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Ipomoea batatas	Yam	dankaly, kudaku, dagafibre,	H, Z, F	Tu	Ipba	cooked	Local market
Sclerocarya birrea	Marula	daniya, diney (luley), hedi,	H, Z, F	Am	Scbi	grid	Local market
Pennisetum glaucum	Millet	hatsi;hayni;gawuri	H, Z, F	Gr	Pegl	grid	Niamey
Hyphaene thebaica	Doum Palm	goriba, kangaunya, gellehy,	H, Z, F	Pu	Hyth	believed	Local market
Ziziphus mauritiana	Jujube	magaria, darey, djâbhi,	H, Z, F	Pu	ZimaF	believed	Local market

1: H=Hausa; Z=Zarma; F=Fulfulde. 2: Am = Almond; Pu= Pulp; Gr = Grain;Tu=Tuber. **Source:** [14]**.**

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2.3 . Methodology for determining biochemical parameters

The methodology used in this study varied depending on the biochemical parameters studied.

2.3.1. Water content

The method used for determining water content was proposed by AOAC [15]. It consistedof carrying out differential weighing of the crucibles, containing 5g of sample, before and after passing through the oven at 105°C. The difference in weights before and after drying made it possible to determine the humidity, according to Equation 1.

$$W(\%) = \frac{\mathrm{me} - \mathrm{ms}}{\mathrm{me}} X100 \qquad (1)$$

W: water content in percentage (%)

me: mass of the sample before drying (g)

ms: mass of the sample after drying (g)

2.3.2. Ash content

The method used to determine ash content was described by AOAC (1990). Thus, in a crucible, 2 g of the ground material was incinerated at 550°C for 6 h in a NABERTERM brand muffle furnace, MORE THAN HEAT 30-3000°C, Germany. After cooling in a desiccator, the samples werereweighed. The ash content was expressed as mass percentage,according to Equation 2.

$$C\ (\%) = \frac{\mathrm{m2}}{\mathrm{m1}} X100 \qquad (2)$$

m1: mass of test sample (g)

m2: mass of ash (g).

2.3.3. Cellulose

The crude fiber content was estimated using the Weende method. This method is carried out in two hydrolysisprocesses, one acidic with 1.25% H_2SO_4, whichextracts the sugars and starch, and the other alkaline (basic) with 1.25% NaOH, allowing the proteins to be extracted and part of hemicellulose and

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lignin. Acid-base hydrolyses are separated and isolated by filtration and rinsing with hot water [16]. Cellulose content was calculated using the following formula,according to Equation 3:

$$\text{Cellulose brute} \quad (\%) = \frac{\text{P2} - \text{P3}}{\text{P1}} X100$$

P1: Sample weight;

P2: Weight of the crucible + cellulose + mineral materials

P3: Weight of crucible and mineral materials.

2.3.4. Protein content:

The protein content of the samples was determined by the Kjeldahl method. It consists of an automatic distiller brand UDK 129. It is performed in three phases: mineralization, distillation, and colorimetric dosage (volumetric dosage). The nitrogen and crude protein contents relative to the fresh material were calculated directly and provided by the device using 6.25 as a conversion factor [17].

2.3.5. Lipid content: The fat content of thefoods was determined by the Soxhlet method with gravimetric extraction of lipids. The principle is based on the extraction of a test portion with hexane by percolation. Followed by elimination of The solvent was removed by distillation, and finally by drying the residue was dried in an oven and weighed[18].

2.3.6.Total carbohydrate content: The total carbohydrate content in relation to dry matter was determined using the differential method (method used at thelaboratory level). The calculation was performed using the determined values of protein, lipid, ash, and humidity[13] . The formula used was as follows (Equation 4):

%total carbohydrates/DM = 100 - [%Fat + %protein + %ash] (4)

2.3.7.Determination of energy density:The energy density (ED) was calculated according to the equation of Atwater and Benedict [19].

DE = (9 ×lipids (g) + 4 ×proteins (g) + 4 × carbohydrates (g) + 2 ×cellulose (g)).

21.3.8. Statistical analysis

The data were processed and analyzed using Minitab version 19, SPSS version 25, and Excel 13. The comparison of the means of biochemical parameters was carried out according to Tukey's test at the 5% probability threshold. Finally, the hierarchical ascending classification of foods, comparison of means according to the food category, and correlation between the different physicochemical variables were carried out using SPSS software.

2. RESULTS

2.1. Biochemical characterization of foods

Proteins, lipids, carbohydrates, ash and moisture from fruit seeds, tubers, pulps and kernels

Table 2 presents the biochemical composition of thefruit seeds, tubers, pulps, and kernels. It has awater content of less than 7%. The highest water content was 6.72% in millet seeds (*Pennisetum glaucum*) and the lowest was1.55% (*Anacarduimouest*). Furthermore, the total ash content was higher in the pulp of the doum palm (*Hyphaenethebaïca*) at 7.16% but lower in the seeds of millet (*Pennisetum glaucum*) at a rate of 1.85%. It is clear from this table that legumes and fruit kernels contained the highest levels of proteins and lipids. Thus, the highest protein content was observed in soybean (*Glycine max) at 36.39%, followed by Sclerocarya birrea* almond (30.84%), and the lowest was2.11% in sweet potato (*Ipomoea batatas)*.

Furthermore, the highest lipid content was 60.75% in *Neocarya macrophylla kernel* and 0.20% in sweet potato tubers (*Ipomoea batatas*).In contrast, all fruit pulps, tubers, cereals, and some legumes containedsufficient carbohydrates. For this purpose, the sweet potato tuber was exclusively rich in carbohydrates at a rate of 95.25%, and the lowest value was obtained in the *Sclerocarya birrea* kernel (6.45%). The average moisture, ash, protein, lipid, and carbohydrate content was compared. Thesedifferenceswere not significant within each group.

Table 2: Protein, fat, carbohydrate, ash and moisture contents of fruit seeds, tubers, pulps and kernels

Scientific Names[1]	**Proteins (100g/DM)**	**Fats (100g/ DM)**	**Carbohydrates (/100g /DM)**	**Ashes (100g /DM)**	**Humidities (100g)**
Adansonia Digitata	3,11±0,59^{g}	0,44±0,20^{h}	90,39±2,12^{ab}	6,06±1,6^{a}	5,28±0,48^{abc}
Arachis hypogaea	23,76±1,01^{c}	38,93±5,68^{d}	34,01±4,88^{f}	3,3±0,27^{bcd}	1,69±0,51^{g}

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glycine max	36,39±1,83^{a}	8,54±0,92^{f}	51,22±2,74^{e}	3,86±0,04b^{c}	3,46±0,80^{cdefg}
Ziziphus mauritiana ^{A}	29,40±0,43^{b}	29,79±1,04^{e}	37,79±1,09^{f}	3,02±0,13^{bcd}	3,85±0,74^{bcdef}
Anacarduim occidentale	21,29±1,37^{cd}	48,92±0,40^{c}	27,60±2,12^{g}	2,19±0,48^{d}	1,55±0,77^{g}
Borassus aethiopum	6,18±1,50^{f}	0,83±0,40^{gh}	91,10±1,75^{ab}	1,89±0,07^{d}	5,7±0,50^{ab}
Parkia biglobosa	5,13±0,86^{fg}	0,89±0,24^{gh}	89,71±0,82^{ab}	4,27±0,17^{b}	3,17±0,50^{defg}
Cucurbita SP.	29,39±0,61^{b}	53,71±0,58^{b}	14,03±0,43^{h}	2,87±0,15^{bcd}	2,45±0,29^{efg}
Vigna unguiculata	17,82±2,35^{d}	1,94±0,25^{gh}	77,35±2,56^{d}	2,89±0,06^{bcd}	5,41±0,19^{ab}
Neocarya Macrophylla ^{F}	3,47±0,04^{fg}	0,71±0,18^{gh}	93,01±1,13^{ab}	2,81±0,91^{bcd}	5,58±0,99^{bcde}
Neocarya Macrophylla ^{A}	18,89±1,48^{d}	60,75±0,45^{a}	18,29±2,24^{h}	2,07±0,38^{d}	2,19±0,22^{fg}
Sesamum indicum	24,01±0,66^{c}	60,05±0,53^{a}	12,96±0,18^{f}	2,98±0,22^{bcd}	1,86±0,30^{g}
Ipomoea batatas	2,11±1,11^{g}	0,20±0,10^{h}	95,25±1,36^{a}	2,44±0,64^{cd}	3,17±0,58^{defg}
Sclerocarya birrea	30,84±1,86^{a}	58,64±1,54^{a}	6,45±1,28^{i}	4,07±0,03^{b}	1,76±0,52^{g}
Pennisetum glaucum	10,06±0,90^{e}	5,17±0,41^{fg}	82,92±1,60^{cd}	1,85±0,38^{d}	6,72±0,43^{a}
Hyphaene thebaïca	3,66±1,41^{g}	0,78±0,14gh	88,41±1,65^{bc}	7,16±0,15^{a}	4,43±0,85^{bcd}
Ziziphus mauritiana ^{F}	4,15±0 ,40^{g}	0,85±0,39^{gh}	90,87±0,71^{ab}	4,12±0,34b	4,17±1,15ab

1: F=Fruit Pulp and A=Fruit Kernel

The means on a column sharing no letters are significantly different at the 5% threshold.

Cellulose and energy density of seeds, pulp and kernels of fruits and tubers

Legumes and fruit kernels are extremely rich in cellulose, with the exception of *Vigna unguiculata* (Table 3). For this purpose, the highest values were reported for the almond *Neocarya macrophylla* (26.74%), the seed of *Cucurbita SP* (23.75%), almond of *Sclerocaryabirrea*(18.80%), Ziziphus*mauritiana almond* (17.92%), Western Anacarduim almond*,and* seeds of *Sesamum indicum* (16.29%). The cellulose content of Vigna unguiculata seeds is very low (1.48%). Compared to the calculated energy density, *Neocarya macrophylla almond* presentedthe greatest energy value. The energy values of the analyzedsamplesoscillate between 392.24 and 748.93 Kcal/100g.

Table 3:Water, ash, cellulose and energy density contents

Scientific Names [1]	**Cellulose (g /100g /DM)**	**Energy density (Kcal/100g)**
Adansonia Digitata	8.10±0.23	394.13

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Arachis hypogaea	11.35±0.20	604.13
glycine max	7.84±0.60	442.95
Ziziphus mauritiana [A]	17.92±1.29	572.67
Western Anacarduim	16.42±3.48	668.69
Borassus aethiopum	2.82±0.24	402.21
Parkia biglobosa	14.08±1.28	415.52
Cucurbita SP.	23.75±2.19	704.54
Vigna unguiculata	1.48±0.33	401.06
Neocarya Macrophylla [F]	4.68±0.10	401.65
Neocarya Macrophylla [A]	26.74±1.75	748.93
Sesamum indicum	16.29±2.12	720.91
Ipomoea batatas	2.61±0.11	396.43
Sclerocarya birrea	18.80±3.31	714.50
Pennisetum glaucum	2.76±0.25	423.99
Hyphaene thebaica	10.46±0.23	396.18
Ziziphus mauritiana [F]	2.23±0.10	392.24

1: F=Fruit Pulp and A=Fruit Kernel

2.2. Correlation according to biochemical parameters of fruit seeds, tubers, pulps and kernels

The results of comparisons of the averages of biochemical parameters according to the food category to which the plant species belongs (Table 4), showed that legumes are rich in proteins and they are followed by fruit kernels. Fruit almonds had the highest lipid content. They were also the most abundant in cellulose. Furthermore, the highest carbohydrate contentwas observed in the pulp, cereal, and tuber categories. Finally, the vast majority of mineral elements were found in fruit pulps.

Table 4: Comparison of nutrient content based on food category

Food categories	Proteins	lipids	Carbohydrates	Humidities	Ashes	Cellulose

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Pulps	3.90	0.73	90.48	4.53	4.88	7.91
Cereals	10.06	5.17	82.92	6.72	1.85	2.76
Legumes	26.27	32.63	37.91	2.97	3.18	12.14
Almonds	25.11	49.52	22.53	2.34	2.84	19.97
Tubers	4.14	0.51	93.18	4.44	2.17	2.72
Averages	15.86	21.83	58.90	3.67	3.40	11.08

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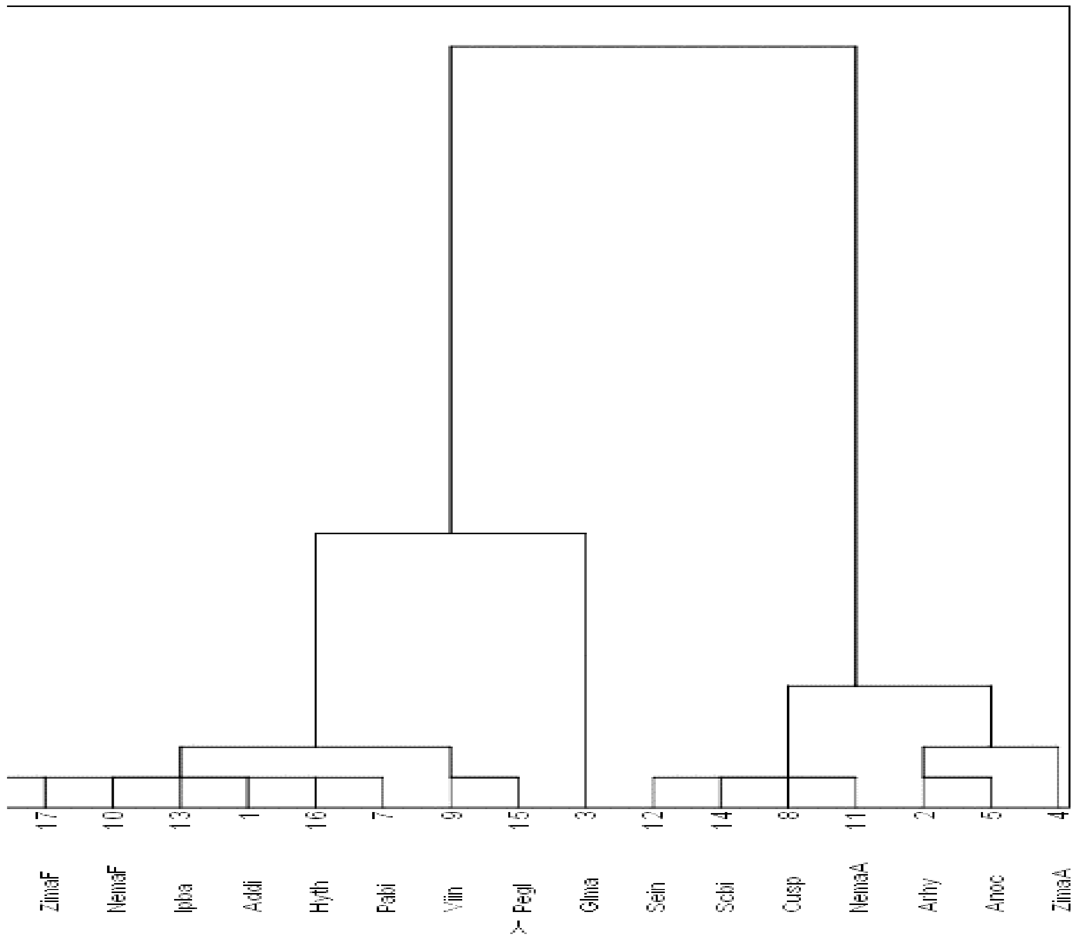

Figure 2: Ascending Hierarchical Classification of samples

The ascending hierarchical classification made it possible to identify three different groups:

-Group 1: Composed of foods such as the tubers of the young shoots of *Borassus aethiopum* (Boae) and Ipomoea *batatas*(Ipba), the fruit pulps of *Ziziphusmauritiana*(ZimaF)*,Neocaryamacrophylla*(NemaF), *Adansoniadigitata (Addi)*, *Hyphaenethebaïca*(Hyth) and*Parkiabiglobosa*(Pabi), the seeds of *vignaunguiculata*(Viun) and *Pennisetumglaucum (*Pegl). It represents 53% of foods and is characterized by high values of carbohydrates and water. However, these foods have low values of proteins,lipids and celluloses.

- Group 2: Composed of foods such as *Sesamum indicum* (Breast) legumes and*Cucurbita SP* (Cusp), the fruit kernels of *Sclerocarya birrea* (Scbi) and *Neocarya macrophylla* (NemaA). It represents 29% of the samples and is characterized by high protein values .

-Group 3: Composed of foods such as *Arachis hypogaea* (Arhy) and *Western Anacarduim*(Anoc) and *Ziziphus mauritiana* (ZimaA). It represents 18% and is characterized by high values of lipids and cellulose but low values of carbohydrates and water.

Table 5 presents the various correlations established between the biochemical measurements. The biochemical parameters from the samples showed positive and significant correlations (r = 0.56, P = 0.0000; r = 0.83, P = 0.0000 and r = 0.69) respectively between the cellulose content and the protein and lipid levels, then between the protein level and the lipid level. On the other hand, a negative and very significant correlation (r = -0.84, P = 0.0000 and r = -0.96;P = 0.0000) was observed between the level of carbohydrates and those of proteins and lipids. Likewise, negative and significant correlations (r = -0.75, P = 0.0000; r = -0.68, P= 0.0000; r = - 0.54, P= 0000) were observed between the humidity level and the lipid level, between the humidity level and the cellulose level as well as between the protein level and the humidity level.

Table 5:Correlation between the different physicochemical variables

		Humidity	Ash	Cellulose	Protein	Lipid	Carbo
Humidity	Corrélation	1					
	Sig. (bilatérale)						
Ash	Corrélation d	0,053	1				
	Sig. (bilatérale)	0,710					
Cellulose	Corrélation	-0,683**	-0,034	1			
	Sig. (bilatérale)	0,000	0,815				
Protein	Corrélation	-0,542**	-0,214	0,565**	1		
	Sig. (bilatérale)	0,000	0,132	0,000			
Lipid	Corrélation	-0,751**	-0,278*	0,837**	0,693**	1	
	Sig. (bilatérale)	0,000	0,048	0,000	0,000		
Carbo[1]	Corrélation	0,741**	0,236	-0,814**	-0,848**	-0,968**	1
	Sig. (bilatérale)	0,000	0,095	0,000	0,000	0,000	

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** The correlation is significant at the 0.01 level (two-tailed).

* The correlation is significant at the 0.05 level (two-tailed).[1] Carbohydrate.

3. DISCUSSION

Niger has plant species that provide numerous products that are used by the generalpopulation,particularly in rural areas. The food use of the latter mainly concerns fruits, pulps, leaves, flowers, seeds, and almonds [20]. The present study involved 15 local plant species,of which 17 were distributed as follows: 4 fruit pulps, 4 fruit almonds, 6 seeds, 2 tubers. Biochemical analyses of all these samples showed very variable contents of proteins, lipids, carbohydrates, cellulose, moisture, and ash (mineral elements), which often vary depending on the plant species, food group, and part concerned (fruit or almond). It is important to note that all data were reported on a dry-matter basis. Most of the previous studies encountered were more interested in raw fibers (total fibers) than cellulose, as well as the different types of minerals and ash contents; hence, these points will be less compared with literature data.

3.1. Moisture, ash, proteins, lipids and carbohydrates

Biochemical characterization of fruit seeds, tubers, pulps, and kernels showed water contents lower than 7%. This low content allows for better conservation [21]. These rates are lower than those reported for Togo on seeds (9 %)[8]. Inthe present study, the highest water content was 6.72%for millet seeds (*Pennisetumglaucum*). It was 5.28% in the pulp of *Adansoniadigitata*, 2.45% in the seeds of *Cucurbita SP,*and 1.55% in the kernel of *Western Anacarduim,*which was the lowest value. These values differ from those of another study conducted in Niger on two species of Cucurbitaceae (*CitrullusColocynthis and Lagenariasiceraria*), whose water content varied from 7 to 9.50% [22]. The baobab pulp was characterized by a water content thatwas close to that found by other authors, which varied from 6 to 15% [23]. In addition, baobab pulp is characterized by its prebiotic potential. Indeed, the fermentation of baobab pulp powder presents characteristics of selective utilization by host microorganisms [24]. The highest total ash contents were observed in the pulps of *Hyphaene thebaïca, Adansonia digitata, Parkia biglobosa, Ziziphus mauritiana* with respective values of 7.16%, 6.06%, 4.27%, 4.12% and that of the lowest in millet

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seeds (*Pennisetumglaucum*) of 1.85%. A high total ash content of 9.7% has been reported for baobab pulp[25].

The present study shows that legumes and fruit kernels contain the highest levels of proteins and lipids. The highest protein content was observed in soybean (*Glycine max) at 36.39%, followed by Sclerocarya birrea* almond (30.84%), and the lowest was 2.11% in sweet potato (Ipomoea batatas). The results obtained are approximately similar to those found in soy varieties consumed in Burkina Fasso and Togo, with protein contents of 31.04% and 34.43 %, respectively[8,26]. According to a previous study in Niger, the kernels of S. birrea fruits constitute a great potential and a very rich composition, reporting contents thatvary depending on the origin from 31.1 to 39.9% of proteins [27]. It is a very fruitful plant, the number of fruits per tree varies from 136 to 4256 with an average fruit weight and diameter of 12.66 and 26.71 mm respectively and the number of almonds varies from 1 to 3 per fruit [28].

The highest lipid contentwasobtained in the kernels of *Neocaryamacrophylla*, *Sclerocaryabirrea*, and *Anacarduimouest*, the seeds of *Sesamumindicum*and *Cucurbita*, respectively 60.75%, 58.64%, 48.92%, 60.05% and 53.71%. These values werehigherthan those of the *Ipomoea tuberbatatas* and fruit pulps of *Adansoniadigitata,*which were 0.20% and 0.44%, respectively. A previous study by Niger noted a higher fat content of 67.5% for the almond *Neocaryamacrophylla*[29]. The observed variations could be linked to the degree of maturity, genetic influence, temperature, sunshine, and nature of the soil. The results of another previous study on the almond of this plant showed that the oil contained myristic acid, palmitic acid, stearic acid, palmitoleic acid, elaidic acid, oleic acid, erucic acid, behenic acid, heneicosanoic acid, icosatetraenoate and eicosatrienoic acid [30,31] . Considering its nutritional benefits, this plant species must be subject to sustainable management because *N. macrophylla* is mainly renewed by sowing (87.6%) and only slightly by stump shoots (11.1%) [32]. Work carried out on *Sclerocarya birrea* almonds in Niger reported contents that varied depending on the origin, from 38 to 56.3% fat, 4.58 to 22.5% carbohydrates, 3.60 to 4, and 58% ash [27]. Other studies have shown variability in nutritional characteristics amongtheprovenances of *Western Anacarduim*. Thus, the highest fat values were noted in nuts from Ziguinchor (54%), followed by those from Sédhiou (44%) and Kolda (37%) [33]. In addition, studies have found similar lipid levels in*Sesamumindicum*of 60.05%, 61.70%, 52.4 to 62.8%, and 49.83% to 59.85%, respectively [34–36].

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The present study also showed that all fruit pulps, tubers, cereals, and some legumes contained sufficient carbohydrates. Indeed, the tubers of sweet potato (*Ipomoea batatas*) and the young shoot of *Borassusaethiopum*, the fruit pulps of *Neocaryamacrophylla*, *Ziziphusmauritiana,*and *Adansonia digitata* are exclusively rich in carbohydrates with respective levels of 95.25%, 91.1%, 93.01%, 90.87%, and 90.39%, and the lowest value was obtained in the kernel of Sclerocarya birrea (6.45%). In Burkina Faso, a similar study on the tuber of *Borassus aethiopum* found a similar carbohydrate content of 86.75% [37]. However, different results were reported for the fruit pulp of *Ziziphus mauritiana,*which was 13.05% [38]. This difference could be explained by the methodology used to determine carbohydrate content (spectrophotometric assay). SimilartoAdansonia*digitata*fruit pulp, different results were reported byBenin 73.12% [39] . This difference in carbohydrate content could be due to the differential method used during the operation, as it inserted the cellulose content.

3.2. Celluloses and energy density

As shown in Table 3, legumes and fruit kernels are extremely rich in cellulose, with exception of *Vignaunguiculata*. Thus, the highest values were reported for the *Neocaryamacrophylla kernel* (26.74%)., the seeds of *Cucurbita SP* (23.75%), almond of *Sclerocaryabirrea*(18.80%), almond of *Ziziphusmauritiana*(17.92%), almond of *Anacarduimouest*, seed of *Sesamumindicum*(16.29%), and seed of *Vignaunguiculata*arevery poor in cellulose (1.48%). Previous studies have reported different cellulose results for *Western Anacarduim,*which varied according to provenance, including Kolda (14%), Ziguinchor (13.5%), and Sédhiou(9%) [33].

Compared to the calculated energy density, *Neocaryamacrophylla almond* had the highest energy value. The energy values of the analyzed samplesoscillate between 392.24 and 748.93 Kcal/100g. The energy richness of fruit almonds and certain legumes could be linked to their high fat content. [8] reported energy values lower than those of this study in the seeds of two legumes *Arachis hypogaea and Sesamum indicum* of 576.08 Kcal and 500.29 Kcal respectively. This difference could be explained by climatic factors and differences in themethodology used to determine carbohydrate levels.

3.3. Correlation according to biochemical and physicochemical parameters of seeds, tubers, pulps and fruit kernels

The results of thecomparison of the averages of the biochemical parameters according to the food category to which the plant species belongs (Table 5) show that legumes have the highest average protein content of 26.27%, which is very close to that of fruit almonds (25.49 %). This could mean thatregardless of whether legumes are available, fruit kernels can be used for their important role in the development, maintenance, and repair of tissues. In addition, fruit almonds had the highest lipid content (49.52 %), followed by that of legumes (32.63 %). However, the fat content varies, depending not only on the species, but also on the part of the fruit studied (pulp or kernel) [40].

In addition, the highest carbohydrate values were observed in the pulp, cereal, and tuber categories with rates of 90.48%, 82.92% and 93.18%, respectively. Almonds were the richest in cellulose(19.97 %), followed by legumes (12.14 %). As for mineral elements, the largest majority was found in fruit pulps with a content of 4.88%, followed by legumes come in second position with a value of 3.18%. The highest water content was observed in cereals (6.72%), followed by pulp (4.53%), which is practically the same for tubers. It emerges from the analysis of this table that all categories of food rich in proteins and lipids have an inverse relationship with the quantity of water. Indeed, foods with the greatest quantities of proteins and lipids were the poorest in water. These results are different from those found in research work in Algeria,where all the energy-rich fruits studied were in an inverse relationship with the quantity of water, andfruits with a high energy content had the poorest water content[40]. This observation is statically confirmed in Table 5with negative and significant correlations at the 0.01 level ($r = -0.75$, $p=0.0000$; $r = -0.68$, $p= 0.0000$; $r= - 0.54$, $p=0000$), which were observed between the humidity level and the lipid level, as well as between the humidity level and the cellulose level, as well as between the protein and lipid level.

Hierarchical ascending classification of the samples revealed three large groups according to their nutritional composition (Figure 2). The first group comprised 53% of the samples and mainly consisted of fruit pulps and starchy foods (tubers) (Boae, ZimaF, NemaF, Ipba, Addi, Hyth, Pabi, Viin, and Pegl). The discriminating criterion was the richness of fruit pulps, starches, and *Vigna unguiculata* in carbohydrates and water. The second group constituted 29%, namely Seal Scbi, Cusp, and Nema. The characteristic criterion of this group wasa high protein value. The third group included 18% of the samples studied,namelyArhy, Anoc, and ZimaA. It is mainly characterized by high values of lipids and cellulose but low values of carbohydrates and water.

Conclusion

At the end of this work, we noted that the plant species studied presented remarkable potential from a nutritional point of view. Plant proteins are present in greater quantities in all almonds and legumes (36.39% for *glycine max*) and can be used in different areassuch as human foodand livestock feed. The oils of fruit kernels and oilseed legumes are present in appreciable quantities, including 60.75% in the *Neocarya macrophylla kernel,*and can have food uses. Pulps, tubers, and cereals exhibited significant energy contributions.

All parts of the plants analyzed are already used in food in Niger, and itis possible to consider different transformations as flour and incorporate it into different food products, either as food supplements or as raw materials.

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