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Fermentation Effect on the Nutrient and Antinutrient Composition of *Senegalia macrostachya* and *Parkia biglobosa* Seeds: A Comparative Study

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Abstract

This study aimed to evaluate the effect of the fermentation on the nutrient and antinutrient composition of *Senegalia macrostachya* and *Parkia biglobosa* seeds. For condiments production, the raw seeds were cleaned, cooked, drained, washed, cooked, drained and fermented. Results show that the pH increased (from 6.09 to 7.76 and from 6.99 to 7.92) from the onset of the fermentation till 48 h during fermentation of *Senegalia macrostachya* and *Parkia biglobosa* seeds respectively. Biochemical analyses revealed a slight increase in water content, ashes, lipids, minerals and a decrease in total carbohydrate for the two products. The fermentation of *Senegalia macrostachya* and *Parkia biglobosa* seeds reduced the initial phytates content by 38.21% and 41.37% respectively. Fermented seeds of *Senegalia macrostachya* are rich in protein (59.59 ± 0.74 g/100g DM), potassium and magnesium (1076.74 ± 37.49 mg/100g DM and 111.63 ± 06 mg/100g DM respectively) with an appreciable iron content (26.27 ± 0.06 mg/100g DM). Given its nutritional composition, fermented seeds of *Senegalia macrostachya* could be used as an alternative to *soumbala* in areas where it is not available.

Keywords

Senegalia macrostachya, *Parkia biglobosa*, Fermentation, Nutrients, Phytates

1. Introduction

In several African countries, alkaline fermented foods are common and form an important part of diet of the indigenous people [1]. Fermentation of seeds is generally carried out to bring diversity into the kinds of foods or to make otherwise inedible foods edible by increasing the nutritional value and decreasing the toxicity [2].

The well-known and the most popular alkaline fermented food in West Africa is the famous *Dawadawa* also known under several names such as *Soumbala*, *Iru*, *Afitin* [1] [3].

In Burkina Faso, *soumbala* resulting from the alkaline fermentation of *Parkia biglobosa* seeds, which has a cheesy taste due to the presence of glutamic acid is still popular and plays an important role as tasty enhancer in many dishes [4] [5]. *Soumbala* or *Koolgo* in the local language, is used in many dishes, usually in sauces where it is directly integrated as a condiment. There are also other types of fermented condiments used as an alternative to *soumbala* in areas where the product is not available. These alternative products include *Maari*, fermented seeds of *Adansonia digitata*, *Bikalga*, fermented seeds of *Hibiscus sabdariffa* and *Mantchoua* fermented seeds of *Ceiba pentandra* [1]. It is also reported that *Senegalia macrostachya* seeds are fermented giving similar product to *soumbala* found in the Central region of Burkina Faso [6]. *Senegalia macrostachya* is a legume highly prized in Burkina Faso through its seeds used in the preparation of *zamné*, a local food [7]. Previous studies on *Senegalia macrostachya* focused on productivity, biochemical characterization of seeds and *zamné* technology [8] [9] [10]. To date no study has focused on the *Senegalia macrostachya* seed fermentation. Hence the need for the present study aims to make a comparative study of the effect of fermentation on the nutrient and antinutrient composition of *Senegalia macrostachya* and *Parkia biglobosa* seeds.

2. Material and Methods

The raw material used for the production of fermented condiments consists of dehulled seeds of *Parkia biglobosa*, seeds of *Senegalia macrostachya* and ash leachate. The sample of *Parkia biglobosa* seeds consists of a mixture of seeds from 3 locations in Burkina Faso (*Péni*, *Nobéré and Louda*). *Senegalia macrostachya* seeds and ash leachate were purchased at a market in Ouagadougou (Naabi-yaré).

Production

The production of the fermented seeds was carried out in workshop-pilot. For each type of seed, two production trials were carried out, and each trial consisted of two parallel fermentations.

For the production of *soumbala*, the dehulled and cleaned seeds of *Parkia biglobosa* were cooked for 6 hours, drained of, washed, cooked a second time for 30 minutes with addition of ash leachate (1%), drained of and leave naturally fermented at room temperature in fermentation tun for 48 hours. The resulting

product was sun dried for 72 hours.

For the production of fermented seeds of *Senegalia macrostachya*, the cleaned seeds were cooked a first time for 30 minutes, drained of, washed, cooked a second time for 30 minutes with addition of ash leachate (1%), drained of and leave fermented at room temperature in fermentation tun with an inoculation from *soumbala* (2%) for 48 hours. The resulting product was sun dried for 72 hours.

Sampling

Raw seeds of *Senegalia macrostachya*, dehulled seeds of *Parkia biglobosa*, samples took at different stages of fermentation (0 h, 12 h, 24 h, 36 h and 48 h) and dry fermented samples were submitted to different analyses.

Microbiological analyses

The determination of the total Mesophilic Aerobic Count (MAC) was carried out according to the NF EN ISO 4833 standard [11].

Biochemical analyses

The measurement of pH was carried out according to AOAC 981.12 using a temperature-compensated pH meter (SI Analytics, Lab 875P) [12]. Water, ash, proteins and fat content were determined according to international standard methods [13] [14] [15] [16]; carbohydrate was determined by the differential method. Minerals (Fe, Zn, Ca, K, Mg) were determined according to AOAC 975.03 using the Atomic Absorption Spectrophotometric Method (Thermo Scientic AA) [17]. The determination of phytates was done according to the method of Latta and Eskin [18].

Statistical analyses

All biochemical analyses were conducted in triplicate. Data were processed to derive means and relative standard deviation. An analysis of variance (ANOVA) followed by Tukey test was carried out to determine statistical differences between samples with a confidence interval of 95%, using the XLSTAT software, version 2015.4.01. 22368. A Principal Component Analysis (PCA) was performed using the FactoMinR package with the RStudio software, version 1.1.463, to visualize the grouping of samples with regard to macronutrients as well as mineral content.

3. Results

Total mesophilic aerobic count

Figure 1 shows the evolution of the total Mesophilic Aerobic Count during the fermentation of *Parkia biglobosa* and *Senegalia macrostachya* seeds.

The load of Mesophilic Aerobic Count of *soumbala* went from 1.1×10^3 CFU/g from the onset of the fermentation (0 h) to 1.6×10^{13} CFU/g at the end of fermentation (48 h).

During the fermentation of seeds of *Senegalia macrostachya*, the Mesophilic Aerobic Count varied from 10 CFU/g at the beginning of fermentation, to 2×10^{10} CFU/g at the end of fermentation.

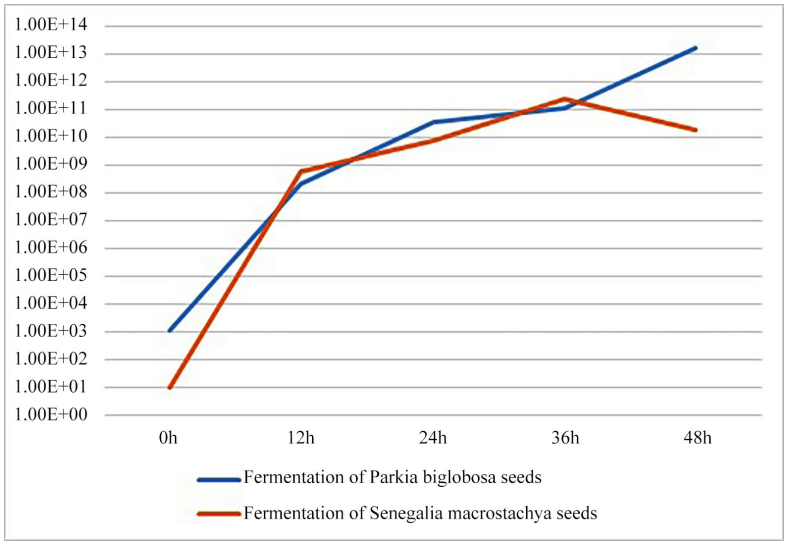

Figure 1. Evolution of the total mesophilic aerobic count during fermentation.

Biochemical characteristics

The biochemical characteristics of *Senegalia macrostachya* and *Parkia biglobosa* seeds changed during fermentation. The pH of *Parkia biglobosa* seeds (Table 1) varied during fermentation from 6.99 ± 0.09 (0 h) to 7.92 ± 0.04 (48 h) and a decrease in pH after drying to about 6.14 ± 0.12 for *soumbala*. That of *Senegalia macrostachya* seeds (Table 1) changed from 6.09 ± 0.01 (0 h) to 7.76 ± 0.34 (48 h) during fermentation. After drying, the pH was 6.23 ± 0.07 for fermented *Senegalia macrostachya* seeds. For both products, there is a significant difference between the pH of the products at the beginning of fermentation (0 - 24 hours) and that of the products at the end of fermentation (36 - 48 hours). The pH of the dry fermented product of *Parkia biglobosa* is different from that of the products during fermentation.

Proximate composition

Table 2 shows the contents of water, ash, lipids, total carbohydrates and proteins (expressed as a percentage of dry matter) in the raw *Parkia biglobosa* and *Senegalia macrostachya* samples as well as samples collected during and after the fermentation process.

The water content of *Parkia biglobosa* dehulled seeds initially 7.21% changed to 66.29% after cooking at the beginning of fermentation and to 63.94% at the end of fermentation. The dry samples of *soumbala* had an average water content of 5.02%. The seeds of *Senegalia macrostachya* had an average water content of 9.58%. At the beginning of fermentation, this content was 79.7% (after cooking) and 82.73% at the end of fermentation. For the dry fermented sample, the average water content was about 5.33%.

Raw seeds of *Parkia biglobosa* and *Senegalia macrostachya* had respectively an ashes content of 4.57% ± 0.13% and 4.11% ± 0.03%. These contents then varied during fermentation from 2.91% ± 0.12% to 3.42% ± 0.24% for seeds of *Parkia biglobosa*, and from 3.24% ± 0.22% to 4.62% ± 0.26% for *Senegalia macros-*

tachya seeds. Dry *soumbala* and dry fermented seeds of *Senegalia macrostachya* had an average ashes content of 3.42% ± 0.41% and 3.8% ± 0.28% respectively.

Dehulled seeds of *Parkia biglobosa* had an average fat content of 24.91% ± 0.04%. Those of the seeds during fermentation ranged from 37.67% ± 0.43% (0 h) to 42.75% ± 0.99% (48 h). The dry *soumbala* had a fat content of 40.47% ± 0.31%.

Table 1. Evolution of pH during fermentation of *Parkia biglobosa* and *Senegalia macrostachya* seeds.

Fermentation time	*Parkia biglobosa*	*Senegalia macrostachya*
0 h	6.99 ± 0.09^{b}	6.09 ± 0.01^{b}
12 h	6.87 ± 0.08^{b}	6.21 ± 0.02^{b}
24 h	6.92 ± 0.3^{b}	6.53 ± 0.23^{b}
36 h	7.66 ± 0.23^{a}	7.5 ± 0.53^{a}
48 h	7.92 ± 0.04^{a}	7.76 ± 0.34^{a}
Dry fermented product	6.14 ± 0.12^{c}	6.23 ± 0.07^{b}
P-value	<0.0001	<0.0001

*In the same column means with the same superscript letters are not significantly different with P > 0.05.

Table 2. Proximate composition of *Senegalia macrostachya* seeds and dehulled seeds of *Parkia biglobosa* before, during and after fermentation.

Product	Fermentation time	Water Content (%)	Ashes (g/100g DM)	Lipids (g/100g DM)	Carbohydrates (g/100g DM)	Proteins (g/100g DM)
Parkia biglobosa	Dehulled seeds	7.21 ± 1.1^{c}	4.57 ± 0.13^{a}	24.91 ± 0.04^{e}	37.99 ± 0.35^{a}	32.53 ± 0.52^{b}
	0 h	66.29 ± 0.27^{a}	2.91 ± 0.12^{b}	37.67 ± 0.43^{d}	17.73 ± 0.48^{b}	41.69 ± 1.03^{a}
	12 h	66.05 ± 0.82^{ab}	2.99 ± 1.01^{b}	37.75 ± 0.54^{d}	16.14 ± 1.62^{bc}	43.12 ± 1.17^{a}
	24 h	65.57 ± 0.97^{ab}	3.01 ± 0.07^{b}	39.07 ± 0.97^{cd}	14.20 ± 2.77^{bcd}	43.72 ± 2.97^{a}
	36 h	65.13 ± 1.02^{ab}	3.23 ± 0.11^{b}	42.32 ± 1.39^{ab}	12.08 ± 2.41^{cd}	42.37 ± 2.47^{a}
	48 h	63.94 ± 0.33^{b}	3.42 ± 0.24^{ab}	42.75 ± 0.99^{a}	10.72 ± 0.84^{d}	43.11 ± 2.46^{a}
	Dry fermented product	5.02 ± 0.28^{d}	3.42 ± 0.41^{ab}	40.47 ± 0.31^{bc}	16.20 ± 1.89^{bc}	39.91 ± 2.12^{ab}
	P-value	<0.0001	0.005	<0.0001	<0.0001	0.003
Senegalia macrostachya	Seeds	9.58 ± 0.15^{c}	4.11 ± 0.03^{ab}	8.40 ± 0.19^{f}	34.75 ± 0.04^{a}	52.74 ± 0.75^{a}
	0 h	79.7 ± 0.43^{b}	3.24 ± 0.22^{d}	12.93 ± 1.0^{e}	29.09 ± 5.79^{ab}	54.74 ± 3.73^{a}
	12 h	79.53 ± 0.32^{b}	3.32 ± 0.1^{cd}	14.65 ± 0.71^{de}	26.62 ± 6.29^{ab}	55.41 ± 3.08^{a}
	24 h	79.85 ± 0.19^{b}	3.33 ± 0.18^{cd}	18.64 ± 1.09^{bc}	25.07 ± 0.58^{ab}	52.96 ± 4.93^{a}
	36 h	82.02 ± 0.32^{a}	4.04 ± 0.13^{b}	21.65 ± 1.88^{b}	24.33 ± 3.77^{ab}	49.98 ± 2.54^{a}
	48 h	82.73 ± 0.6^{a}	4.62 ± 0.26^{a}	25.00 ± 1.27^{a}	18.57 ± 2.65^{b}	51.81 ± 3.79^{a}
	Dry fermented product	5.33 ± 0.26^{d}	3.80 ± 0.28^{bc}	17.00 ± 0.98^{cd}	19.61 ± 3.87^{b}	59.59 ± 0.74^{a}
	P-value	<0.0001	<0.0001	<0.0001	0.003	0.403

*In the same column for the same product, means with the same superscript letters are not significantly different with P > 0.05.

As for the raw seeds of *Senegalia macrostachya*, they had an average fat content of 8.4% ± 0.19%. This content then varied from 12.93% ± 1.0% (0 h) to 25% ± 1.27% (48 h). The dry fermented seeds had an average fat content of 17% ± 0.98%.

The carbohydrates content of *Parkia biglobosa* seeds was 37.99% ± 0.35% in relation to dry matter. That of the samples during fermentation ranged from 17.73% ± 0.48% (0 h) to 10.72% ± 0.84% (48 h). The dry *soumbala* contained 16.20% of carbohydrates.

Raw seeds of *Senegalia macrostachya* contained 34.75 ± 0.04 of carbohydrates. This content then varied from 29.09% ± 5.79% (0 h) to 18.57%/MS (48 h) during fermentation. After drying, dry fermented *Senegalia macrostachya* seeds had a total sugar content of 19.61% ± 3.87%.

Raw *Parkia biglobosa* seeds contained 32.53% ± 0.52% of proteins. This content varied during fermentation 41.69% ± 1.03% at (0 h) and reached the value of 43.11% ± 2.46% at the end of fermentation (48 h). After drying, this content was 39.91% ± 2.12%.

The proteins content of the raw seeds of *Senegalia macrostachya* was 52.74% ± 0.75%. At the beginning of fermentation (0 h), it was 54.74% ± 3.73% and estimated at the end of fermentation (48 h), at 51.81% ± 3.79%. The dry fermented product had a content of 59.59% ± 0.74%.

Statistical analyses showed a significant difference between the composition of raw seeds and those in fermentation (0 - 36 hours) and between the composition of seeds at 48 hours of fermentation and dry products for *Senegalia macrostachya* and *Parkia biglobosa* ($P < 0.0001$) between the lipids content of dehulled seeds of *Parkia biglobosa* and seeds of *Senegalia macrostachya*. The same difference is observed for dry fermented products. No difference was observed for the other parameters. For the same product, there is a significant difference between raw seeds, seeds in fermentation from 0 to 48 hours and dry fermented products.

Phytates content

The phytates content of raw and fermented seeds of *Parkia biglobosa* and *Senegalia macrostachya* are recorded in **Table 3**. The phytates content is expressed in mg per g of dry matter.

The phytates content varied during fermentation of *Parkia biglobosa* seeds and at the end of drying was 6.81 ± 0.69 mg/g DM. Statistical analysis showed a significant difference between the phytates content of the raw seeds and those of the other samples ($P < 0.0001$). Samples at 36 hours, 48 hours of fermentation and finished product were not significantly different. The phytates content of *Senegalia macrostachya* seeds was 15.28 ± 0.36 mg/g DM. This content then ranged from 12.34 ± 0.31 (0 h) to 8.25 ± 3.29 mg/g DM in the dry fermented product. There is a significant difference ($P = 0.000$) between the phytates content of the raw seeds and those in fermentation (24 - 48 hours). Samples at 24, 36 and 48 hours of fermentation and finished product were not sig-

nificantly different. There is also a significant difference between the phytates content of dehulled seeds of *Parkia biglobosa* and *Senegalia macrostachya* seeds.

Figure 2 presents the Principal Component Analysis (PCA) of the nutrient and antinutrient composition of raw seeds, fermented samples and finished products of *Parkia biglobosa* and *Senegalia macrostachya*.

The main axes Dim1 and Dim2 account for 75.5% of the total inertia, with 50.1% and 24.4% respectively. This analysis gives, in relation to the vertical axis Dim1, a good representativeness of the parameters Fat (29.93%), carbohydrates (27.83%) and phytates (21.75%) and a good representativeness of the parameters proteins (33.01%) and water (42.47%) in relation to the horizontal axis Dim2.

The samples are grouped according to their nature. Raw seeds (PR and SR) around carbohydrates, ashes and phytates translates that they are richer in these biochemical compounds. The samples during fermentation have the highest water, fat and protein contents. The dry finished products (PD and SD) have the lowest contents for all parameters.

Table 3. Phytates content of *Senegalia macrostachya* seeds and dehulled seeds of *Parkia biglobosa* before, during and after fermentation.

Product	Fermentation time (mg/g DM)	Phytates (mg/g DM)
Parkia biglobosa	Dehulled seeds	11.99 ± 0.86^{a}
	0 h	11.72 ± 0.48^{a}
	12 h	10.45 ± 1.2^{ab}
	24 h	9.06 ± 0.71^{bcf}
	36 h	7.43 ± 0.18^{cd}
	48 h	7.03 ± 0.43^{d}
	Dry fermented product	6.81 ± 0.69^{d}
	P-value	<0.0001
Senegalia macrostachya	Seeds	15.28 ± 0.36^{a}
	0 h	12.34 ± 0.31^{ab}
	12 h	12.07 ± 0.63^{ab}
	24 h	10.80 ± 0.66^{bc}
	36 h	9.90 ± 0.17^{bc}
	48 h	9.44 ± 0.55^{bc}
	Dry fermented product	8.25 ± 3.29^{c}
	P-value	0.000

*Means with the same superscript letters for the same product are not significantly different with P > 0.05.

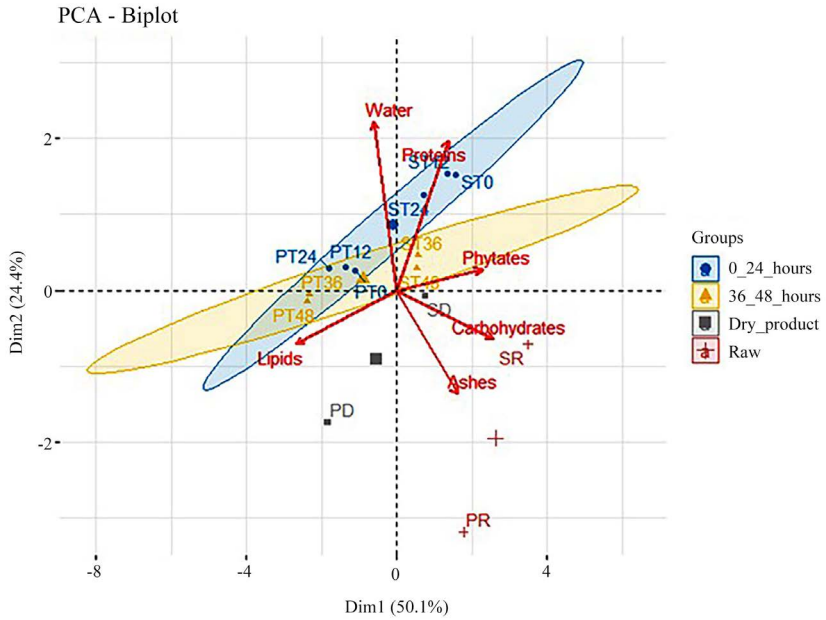

Figure 2. PCA biplot of the nutrient and antinutrient composition of *Parkia biglobosa* and *Senegalia macrostachya* seeds, before, during and after fermentation. S: *Senegalia macrostachya* Seeds; P: *Parkia biglobosa* seeds; R: Raw seeds; D: Dry fermented product; T0: Seeds at 0 hours of fermentation; T12: Seeds at 12 hours of fermentation; T24: Seeds at 24 hours of fermentation; T36: Seeds at 36 hours of fermentation; T48: Seeds at 48 hours of fermentation.

Mineral content

The mineral analysis covered 05 elements: iron, zinc, magnesium, calcium and potassium. Table 4 presents the mineral contents of the samples of *Parkia biglobosa* and *Senegalia macrostachya* expressed in mg per 100 g of dry matter.

The mean iron content of raw seeds of *Parkia biglobosa* was estimated at 8.35 ± 0.15 mg/100g dry matter. This content then varied from 7.72 ± 1.07 (0 h) to 11.09 ± 0.82 mg/100g DM (48 h). After drying, the content was estimated to be 5.40 ± 0.13 mg/100g dry matter. That of raw seeds of *Senegalia macrostachya* was 34.02 ± 0.20. This content then varied during fermentation from 8.41 ± 0.21 (0h) to 25.85 ± 11.02 mg/100g (48 h). After drying, the iron content of the fermented product was 26.27 ± 0.06 mg/100g.

As for zinc and magnesium, their contents were estimated respectively at 3.05 ± 0.06 and 46.11 ± 0.85 mg/100g in raw seeds of *Parkia biglobosa*; and at 12.42 ± 0.07 and 187.82 ± 1.08 mg/100g DM in raw seeds of *Senegalia macrostachya*. These levels then varied throughout fermentation and after drying. They were estimated respectively at 4.47 ± 0.09 and 178.84 ± 1.74 mg/100g in dry *soumbala* and those of dry fermented seeds of *Senegalia macrostachya* respectively at 7.25 ± 0.14 and 111.63 ± 0.6 mg/100g.

Calcium content ranged from 244.37 ± 4.49 in raw seeds of *Parkia biglobosa* to 589.59 ± 5.91 mg/100g in dry *soumbala* and potassium content ranged from 287.54 ± 5.28 to 605.48 ± 14.35 mg/100g. Raw seeds of *Senegalia macrostachya* contained 995.53 ± 5.73 mg/100g of calcium, and 1171.38 ± 6.74 mg/100g of po-

tassium. These levels varied during fermentation and were 645.43 ± 51.28 mg/100g and 1076.74 ± 37.49 mg/100g for calcium and potassium respectively in the dry end product.

Statistical analysis shows a significant difference between the contents of the different mineral in the samples ($P < 0.0001$). For the two products, there is no difference between the mineral content of raw seeds and final product except magnesium, calcium and potassium for *Parkia biglobosa* and magnesium for *Senegalia macrostachya*.

Figure 3 shows the Principal Component Analysis (PCA) of minerals in raw seeds, fermented samples and finished products of *Parkia biglobosa* and *Senegalia macrostachya*.

The main axes Dim1 and Dim2 represent 93.9% of the total inertia with 82.9% and 11.00% respectively. This analysis gives, in relation to the vertical axis Dim1, a better representativeness of the parameters calcium (23.17%), potassium (21.84%) and iron (20.17%). With respect to the horizontal axis Dim2, a good representativeness of the magnesium parameter (62.21%) is observed. A clustering of raw samples of *Parkia biglobosa* and *Senegalia macrostachya* around the elements calcium and potassium is observed. The samples from 0 to 24 hours of fermentation are grouped opposite all the mineral elements and the dry fermented samples close to the magnesium parameter.

Table 4. Mineral content of *Senegalia macrostachya* seeds and dehulled seeds of *Parkia biglobosa* before, during and after fermentation.

Product	Fermentation time	Fe (mg/100g DM)	Zn (mg/100g DM)	Mg (mg/100g DM)	Ca (mg/100g DM)	K (mg/100g DM)
Parkia biglobosa	Dehulled seeds	8.35 ± 0.15^{ab}	3.05 ± 0.06^{b}	46.11 ± 0.85^{bc}	244.37 ± 4.49^{bc}	287.54 ± 5.28^{bc}
	0 h	7.72 ± 1.07^{ab}	2.82 ± 0.39^{b}	42.62 ± 5.89^{c}	225.88 ± 31.22^{c}	232.73 ± 3.24^{c}
	12 h	10.41 ± 1.07^{a}	4.44 ± 0.31^{b}	57.46 ± 5.89^{bc}	304.54 ± 31.25^{bc}	358.34 ± 36.77^{bc}
	24 h	11.36 ± 1.94^{a}	5.51 ± 0.79^{ab}	62.74 ± 10.71^{bc}	332.53 ± 56.77^{bc}	391.28 ± 66.80^{bc}
	36 h	11.59 ± 3.36^{a}	8.24 ± 1.61^{a}	79.39 ± 25.24^{b}	420.82 ± 133.77^{ab}	495.15 ± 157.4^{ab}
	48 h	11.09 ± 0.82^{a}	8.36 ± 2.38^{a}	79.36 ± 15.69^{b}	420.64 ± 83.15^{ab}	494.94 ± 97.84^{ab}
	Dry fermented product	5.40 ± 0.13^{b}	4.47 ± 0.09^{b}	178.84 ± 1.74^{a}	589.59 ± 5.91^{a}	605.48 ± 14.35^{a}
	P-value	0.002	<0.0001	<0.0001	0	0
Senegalia macrostachya	Seeds	34.02 ± 0.20^{a}	12.42 ± 0.07^{a}	187.82 ± 1.08^{a}	995.53 ± 5.73^{a}	1171.38 ± 6.74^{a}
	0 h	8.41 ± 0.21^{b}	3.07 ± 0.08^{b}	46.43 ± 1.18^{e}	246.11 ± 6.25^{c}	289.58 ± 7.36^{c}
	12 h	8.67 ± 0.16^{b}	4.67 ± 0.16^{b}	58.26 ± 11.84^{de}	374.69 ± 12.51^{bc}	363.36 ± 73.84^{bc}
	24 h	9.45 ± 0.23^{b}	6.94 ± 5.45^{ab}	52.17 ± 1.27^{e}	275.40 ± 8.40^{c}	657.71 ± 511.31^{abc}
	36 h	22.08 ± 4.38^{a}	8.06 ± 1.6^{ab}	121.93 ± 24.20^{b}	646.26 ± 128.28^{ab}	760.42 ± 150.94^{abc}
	48 h	25.85 ± 11.02^{a}	9.44 ± 4.02^{ab}	83.12 ± 4.82^{cd}	647.96 ± 309.83^{ab}	1050.60 ± 402.83^{ab}
	Dry fermented product	26.27 ± 0.06^{a}	7.25 ± 0.14^{ab}	111.63 ± 0.6^{bc}	645.43 ± 51.28^{ab}	1076.74 ± 37.49^{a}
	P-value	<0.0001	0.014	<0.0001	<0.0001	<0.003

*In the same column for the same product, means with the same superscript letters are not significantly with $P > 0.05$.

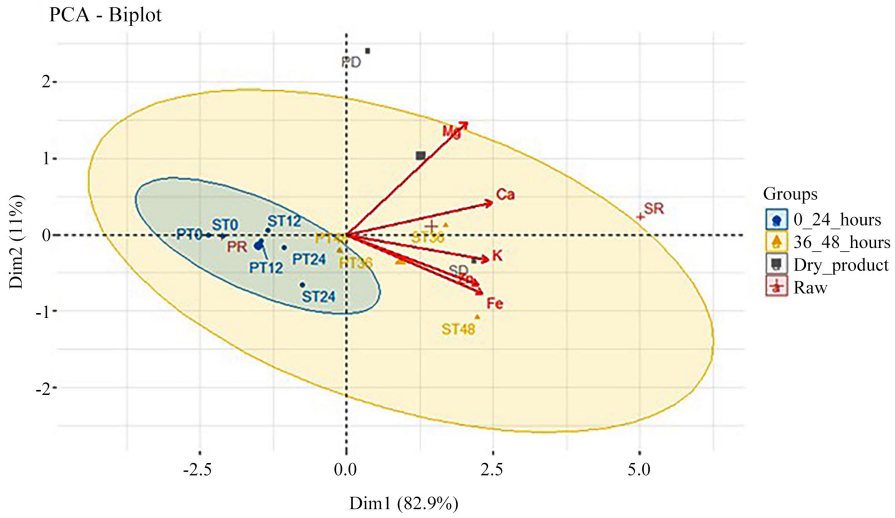

Figure 3. PCA biplot of the mineral composition of *Parkia biglobosa* and *Senegalia macrostachya* seeds, before, during and after fermentation. S: *Senegalia macrostachya* Seeds; P: *Parkia biglobosa* seeds; R: Raw seeds; D: Dry fermented product; T0: Seeds at 0 hours of fermentation; T12: Seeds at 12 hours of fermentation; T24: Seeds at 24 hours of fermentation; T36: Seeds at 36 hours of fermentation; T48: Seeds at 48 hours of fermentation.

4. Discussion

The aerobic mesophilic flora

The total Mesophilic Aerobic Count increases from 0 h to 48 h during the production of *soumbala* and fermented seeds of *Senegalia macrostachya*. A strong growth of the flora was observed during the first 24 hours and a slower increase between 24 and 36 hours for both products. After 36 hours, we observe a rebound of growth for *soumbala* and a decrease for the seeds of *Senegalia macrostachya*. This decrease could reflect a saturation of the environment with non-availability of nutrients. These variations show a strong microbial multiplication during seed fermentation. This strong multiplication was also observed by Sawadogo/Lingani *et al.* [19] during the fermentation of *soumbala* from dehulled seeds, with a microflora that went from 1.6×10^4 - 5.3×10^4 CFU/g at the beginning of fermentation to 1.2×10^8 - 2.1×10^{11} CFU/g at the end of fermentation. Okhonlaye and Olabisi [20] in a study on fermented seeds of *Hibiscus sabdariffa L.* attributed the high bacterial loads of fermented condiments to the alkaline adjuvants used during production, which would increase the pH of the medium, thereby promoting bacterial growth. Indeed, this microflora forms a set of microorganisms capable of aerobic growth at neutral pH and the optimal growth temperature of 25˚C - 45˚C.

Biochemical characteristics

The evolution of pH during fermentation of *Senegalia macrostachya* seeds and those of *Parkia biglobosa* are similar. However, the pH values during fermentation of *Senegalia macrostachya* seeds remain lower than those of *Parkia biglobosa* seeds. Compared to this study, Sawadogo/Lingani *et al.* [19] during fermentation of *Parkia biglobosa* seeds reported pH values of 5.4 - 5.8 at 0 h of fermenta-

tion lower than those of the present study. At the end of fermentation (48 h) and on the dried product, they report respectively values of 8.4 - 8.9 and 6.3 - 6.6 higher than the values found.

The low pH values observed during fermentation of *Senegalia macrostachya* seeds could be explained by the difference in pH existing in the raw materials. Indeed, seeds of *Senegalia macrostachya* would have a pH of 5.65 ± 0.01 lower than those of raw seeds of *Parkia biglobosa* which have a pH of 6.2 [9] [21]. The difference in pH at 0 hours of fermentation observed with the values reported by Sawadogo/Lingani *et al.* [19] could be explained by the addition of ash leachate for seed cooking in the present study (1%) that these authors did not use. An increase in pH was observed between 0h and 48h of fermentation and a decrease after drying of the products. The similarity of the pH evolution during fermentation of the two types of products could reflect a similarity in microbial activity. Indeed, the fermentation of *Senegalia macrostachya* seeds was initiated by the addition of *soumbala*. The same observation has been made by several authors [19] [21]. This increase is related to the pronounced release of nitrogen compounds (ammonia) in the medium [22] [23].

Raw seeds of *Parkia biglobosa* had an ash content higher than the values reported by Koura *et al.* [24] and Elemo *et al.* [25], which were 3.51% - 4.39% and 4.24% respectively. However, they presented lower values than those found by Omafuvbe *et al.* [21] which were 5.4% ± 0.3%. Crude seeds of *Parkia biglobosa* had protein and lipid contents close to those reported by these authors respectively 24.33% - 33.56% and 15.48% - 22.56% [21] [24] [25]. The carbohydrates content is within the range of these authors (34.5% - 41%). The mineral contents are higher than those reported by Olujobi [26] which were 50.67 ± 2.52 - 53.19 ± 0.02 mg/kg for iron, 28.67 ± 0.06 - 30.6 ± 2.52 mg/kg for magnesium and 1428.12 ± 0.02 - 1470.33 ± 4.50 mg/kg for calcium. As for the raw seeds of *Senegalia macrostachya*, they had a higher water content than the values reported by Savadogo *et al.* [8] which was 6.02% - 6.99%. The ash and fat contents are in agreement with those reported by this author (respectively 3.34% - 4.97% and 8.66% - 9.31%) and the carbohydrates and proteins contents higher (20% - 29.1% and 10.44% - 13.06%). The potassium and calcium contents are higher than the values reported by Savadogo *et al.* [8] which were respectively 10.45 - 14.6 mg/100g and 20 - 40 mg/100g. The difference in composition between our samples and those of the other authors could be explained by the difference in origin, but also by the difference in treatment and analysis methods. Indeed, the samples used by Elemo *et al.* [25] were dehulled, dried and defated before analysis.

After cooking the seeds, there was an increase in the water, lipids and proteins content of seeds and a decrease in the content of ashes, minerals, carbohydrates and phytates. The increase in water content is thought to be due to water absorption by the seeds during cooking [27] [28]. The loss of total ashes and mineral elements could be explained by a disorganization of the complexes under which minerals are found in organic matter during cooking resulting in a diffusion of soluble salts from the food to the cooking water [29] [30]. The decrease

in carbohydrates content could be explained by the different degradation, solubilization and transformation reactions of sugars that take place during water cooking, especially by the hydrolysis of the osidic bonds in alkaline medium [30]. The variation in phytates content could be due to heat deactivation. This decrease in phytates content during cooking corroborates the statement of Rémond and Walrand [31] "soaking, cooking, germination and fermentation make it possible to significantly reduce the phytates content of the baked product". The increase in protein content after cooking could be related to destructuring of thermolabile anti-nutritional (anti-trypsic) factors [27]. This increase in protein content and that of lipids could be linked to a compensation of content due to the loss of ash and total sugars [21].

During fermentation, a decrease in water content is observed for seeds of *Parkia biglobosa* and a slight increase for those of *Senegalia macrostachya*. Also, there is a decrease in carbohydrates and phytate content and an increase in ashes, minerals, lipids and proteins content. The same observations have been made by several authors during the production of fermented condiments [21] [32]. According to Azokpota *et al.* [32], the decrease in water content could be related to evaporation or draining through the fermentation matrix. He attributes the decrease in carbohydrates to the activity of microorganisms that derive their energy from carbohydrates metabolism. The increase in ashes and proteins content would be linked to one hand to a compensation due to the decrease in carbohydrates content [21]. It could also be linked to a deactivation of anti-nutritional factors. Indeed, phytates have chelating properties and form complexes with minerals, but also with proteins [33]. The phytic acid present in the seeds blocks the release of minerals and thus constitutes a major obstacle to their absorption. Thus, phytate degradation during fermentation can increase the availability of some minerals [34].

5. Conclusion

The study on the production of fermented condiment from the *Senegalia macrostachya* seeds reveals a similarity in the evolution of the parameters during fermentation with that of the production of *soumbala*. The results of the analyses show a high microbial load and an increase in pH making the medium alkaline. The fermentation of *Senegalia macrostachya* seeds as well as *soumbala* leads to an improvement of the nutritional quality of these seeds by increasing the fats and proteins content and decrease of the phytate content. Fermented seeds of *Senegalia macrostachya* have composition close to that of *soumbala* and could be used as an alternative to *soumbala* in areas where it is not available. The high proteins and iron content could make this condiment a complement used in the substitution of animal proteins and in the prevention of anaemia due to iron deficiency for women and children.

Conflicts of Interest

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

References

[1] Parkouda, C., Nielsen, D.S., Azokpota, P., Ouoba, L.I.I., Amoa-Awua, W.K., Thorsen, L., Hounhouigan, J.D., Jesen, J.S., Tano-Debrah, K., Diawara, B. and Jakobsen, M. (2009) The Microbiology of Alkaline-Fermentation of Indigenous Seeds Used a Food Condiment in Africa and Asia. *Critical Reviews in Microbiology*, **35**, 139-156. https://doi.org/10.1080/10408410902793056

[2] Steinkraus, K.H. (1996) Handbook of Indigenous Fermented Foods. 2nd Edition, Revised and Expanded, Marcel Decker, New York.

[3] Dakwa, S., Sakyi-Dawson, E., Diako, C., Nana, T.A. and Amoa-Awua, W.K. (2005) Effect of Boilling and Roasting on the Fermentation of Soybeans into Dawadawa (Soy-Dawadawa). *International Journal of Food Microbiology*, **104**, 69-82. https://doi.org/10.1016/j.ijfoodmicro.2005.02.006

[4] Malouba, P. (2002) Comparative Study of the Stability of Soumbala Packaged in Three Types of Packaging. Master Dissertation, University of Ouagadougou, Ouagadougou.

[5] Ouoba, L.I. (2003) Genotypic and Biochemical Characterization and Antimicrobial Activity of Bacillus Spp. for the Development of Starters for the Controlled Production of Soumbala. Ph.D. Dissertation, University of Ouagadougou, Ouagadougou.

[6] Millogo-Rasolodimby, J. and Guinko, S. (1996) Spontaneous Woody Plants for Culinary Use in Burkina Faso. *Berichte des Sonderforschungsbereichs*, **268**, 125-133.

[7] Ganaba, S. (2017) Characterization of a Wild Food Legume, the Zamnè Tree. INERA.

[8] Savadogo, A., Ilboudo, A.J. and Traoré, A.S. (2011) Nutritional Potentials of *Acacia macrostachya* (*Reichend*) *ex Dc* Seeds of Burkina Faso: Determination of Chemical Composition and Functional Properties. *Journal of Applied Sciences Research*, **7**, 1057-1062.

[9] Guissou, A.W.D.B., Parkouda, C., Ganaba, S. and Savadogo, A. (2017) Technology and Biochemical Changes Associated with the Production of Zamne: A Traditional Food of *Senegalia macrostachya* Seeds from Western Africa. *Journal of Experimental Food Chemistry*, **3**, 131-135. https://doi.org/10.4172/2472-0542.1000131

[10] Sawadogo, Y., Ganaba, S., Tindano, E. and Nacro, H.B. (2018) Allometric Model for the Prediction of the Fruit Production of *Senegalia macrostachya* (*Reichenb. ex DC.* Kal & Boatwr) North-South in Burkina Faso.

[11] Norme NF EN ISO 4833 (2003) Food Microbiology. Horizontal Method for Enumeration of Microorganisms. Colony Counting Technique at 30˚C.

[12] AOAC (1999) Official Methods of Analysis of AOAC International. Food Composition, Additives, Natural Contaminants. 16th Edition, AOAC International, Gaithersburg, MD, USA, 35-47.

[13] International Standard ISO 20483 (2013) Cereals and Pulses—Determination of the Nitrogen Content and Calculation of the Crude Protein Content—Kjeldahl Method. 2nd Edition, 14.

[14] International Standard ISO 659 (2009) Determination of Oil Content (Reference Method) in Oilseeds. 4th Edition, 13.

[15] International Standard ISO 712 (2009) Determination of Moisture Content-Reference Method in Cereals and Cereal Products. 4th Edition, 17.

[16] International Standard ISO 2171 (2007) Determination of Ash Content by incineration in Cereals, Pulses and Derived Products. 4th Edition, 11.

[17] AOAC (2005) Official Method Analysis 975.03. Metals in Plants and Pets Food

Atomic Absorption Spectrophotometric Method.

[18] Latta, M. and Eskin, M. (1980) A Simple and Rapid Colorimetric Method for Phytate Determination. *Journal of Agricultural and Food Chemistry*, **28**, 1313-1315. https://doi.org/10.1021/jf60232a049

[19] Sawadogo-Lingani, H., Diawara, B., Ganou, L., Gouyahali, S., Halm, M., Amoa-Awua, W. and Jakobsen M. (2003) Effect of Mechanical Dehulling on the Fermentation of Nere (*Parkia biglobosa*) Seeds in Soumbala. *Annals of Agronomic Sciences of Benin*, **5**, 67-84.

[20] Okhonlaye, O.A. and Olabisi, A.O. (2017) Effects of Fermentation on Nutritional and Microbial Qualities of Ash Neutralized Roselle (*Hibiscus sabdariffa L.*). *International Journal of Biochemistry Research & Review*, **16**, 1-8. https://doi.org/10.9734/IJBCRR/2017/30168

[21] Omafuvbe, B.O., Falade, O.S., Omuntogun, B.A. and Adewusi, S.R.A. (2004) Chemical and Biochemical Changes in African Locust Bean (*Parkia biglobosa*) and Melon (*Citullus vulgaris*) Seeds during Fermentation to Condiments. *Pakistan Journal of Nutrition*, **3**, 140-145. https://doi.org/10.3923/pjn.2004.140.145

[22] Diawara, B., Sawadogo, L., Wisdom, K. and Mogens, J. (1998) Quality System for the Production of Soumbala: The HACCP System.

[23] Omafuvbe, B.O., Shonukan, O.O. and Abiose, S.H. (2000) Microbiological and Biochemical Changes in the Traditional Fermentation of Soy Bean for "Soy-Daddawa"—Nigerian Food Condiment. *Food Microbiology*, **17**, 469-474. https://doi.org/10.1006/fmic.1999.0332

[24] Koura, K., Peace, I.G.O., Azokpota, P., Ganglo, J.C. and Hounhouigan, D.J. (2014) Caractérisation Physique et Composition Chimique des Graines de Parkia Biglobosa (Jacq.) R. Br. en Usage au Nord-Bénin. *Journal of Applied Biosciences*, **75**, 6239-6249. https://doi.org/10.4314/jab.v75i1.4

[25] Elemo, G.N., Elemo, B.O., Oladunmoye, O.O. and Erukainure O.L. (2011) Comprehensive Investigation into the Nutritional Composition of Dehulled and Defatted African Locust Bean Seed (*Parkia biglobosa*). *African Journal of Plant Science*, **5**, 291-295.

[26] Olujobi, O.J. (2012) Comparative Evaluation of Nutritional Composition of African Locust Bean (*Parkia biglobosa*) Fruits from Two Locations. *Nigerian Journal of Basic and Applied Science*, **20**, 195-198.

[27] Opai-Tetteh, S. (1999) The Microbial Activities involved in the Alkaline Fermentation of Soybeans into Dawadawa. Master Dissertation, University of Ghana, Ghana.

[28] Chukwu, O., Orhevba, B.A. and Babatunde, I.M. (2010) Influence of Hydrothermal Treatments on Proximate Compositions of Fermented Locuct Bean (Dawadawa). *Journal of Food Technology*, **8**, 99-101. https://doi.org/10.3923/jftech.2010.99.101

[29] Nout, R., Hounhouigan, J.D. and Van, B.T. (2003) Food, Processing, Preservation and Quality. Backhuys Publishers, Leiden.

[30] Compaoré, S.C. (2009) Production Monitoring and Study of the Biochemical and Microbiological Characteristics of Maari: A Fermented Condiment Made From Baobab (*Adansonia digitata*) Grains. Master Dissertation, University of Ouagadougou, Ouagadougou.

[31] Rémond, D. and Walrand, S. (2017) Legume Seeds: Nutritional Characteristics and Health Effects. *Agronomic Innovations*, **60**, 133-144.

[32] Azokpota, P., Hounhouigan, D.J. and Nago, M.C. (2006) Microbiological and Chemical Changes during the Fermentation of African Locust Bean (*Parkia biglobosa*) to

Produce *Afitin*, *Iru* and *Sonru*, Three Tarditional Condiments Produced in Benin. *International Journal of Food Microbiology*, **107**, 304-309. https://doi.org/10.1016/j.ijfoodmicro.2005.10.026

[33] Gabriel, C. (1999) Digestion des Protéines Végétales Chez les Monogastriques. Exemple des Protéines de Pois. *INRAE Productions Animals*, **12**, 147-161. https://doi.org/10.20870/productions-animales.1999.12.2.3874

[34] Senapathi, A.K., Kumari, A., Raj, D., Prajapati, J.P., Sandhu, K.S., Angmo, K., Taweechotipatr, M., Chandel, R., Pinto, S.V.S., Tanasupawat, S., Sharma, S., Thorat, S.S. and Bhalla, T.C. (2015) Traditional Fermented Foods, Composition and Nutritive Value. In: Joshi, V.K., Ed., *Indigenous Fermented Foods of South Asia*, Chap. 4, CRC Press, Boca Raton.