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Microbiological quality and sensory evaluation of *Soumbara*-type fermented condiments produced from alternative legumes to *néré*

Sika Hortense Blei[1]*, Affoué Tatiana Kouassi[1], Adjoua Christiane Eunice Boko[2], Djédoux Maxime Angaman[1]
[1] Laboratory of Agro-valorization, Jean Lorougnon Guédé University, Daloa, Côte d'Ivoire
[2] Laboratory of Biochemistry, Biotechnology and Food Science, Alassane Ouattara University, Bouaké, Côte d'Ivoire
*Correspondence: Sika Hortense Blei (hortense.bleisika@gmail.com)

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ABSTRACT
Objectives : The increasing scarcity of *Parkia biglobosa* (*néré*) seeds threatens the sustainability of traditional *Soumbara*, a fermented condiment widely consumed in West Africa, production. This study aimed to evaluate the microbiological quality and sensory acceptability of *Soumbara*-type fermented condiments produced from alternative legumes, soybean (*Glycine max*), *Bambara* groundnut (*Vigna subterranea*) and cowpea (*Vigna unguiculata*), using spontaneous and controlled fermentation processes.
Methodology and results : Five experimental formulations, including single-legume and mixed-legume products fermented with or without *Bacillus* starter cultures (*Bacillus subtilis* vav15 and *Bacillus velezensis* vav16), were compared with traditional *néré*-based *Soumbara*. Microbiological analyses showed that all fermented products had satisfactory sanitary quality, with aerobic mesophilic counts below 10^4 CFU/g, low coliform levels, and absence of *Salmonella spp.*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*. Sensory evaluation conducted with 60 untrained consumers revealed significant differences among formulations ($p < 0.05$) for taste, texture and overall acceptability. The soybean-*Bambara* groundnut formulation fermented with starter cultures recorded the highest scores for taste (5.47 ± 1.92) and overall acceptability (5.57 ± 1.63), comparable to those of traditional *Soumbara*.
Conclusion and application of results :The results demonstrate that soybean and *Bambara* groundnut are suitable alternatives to *néré* for the production of *Soumbara*-type fermented condiments. Using controlled fermentation of mixed-legume formulations with selected *Bacillus* starter cultures yields condiments that achieve microbiological safety and sensory qualities comparable to traditional Soumbara. This innovation reduces reliance on *Parkia biglobosa*, enhances the value of locally available legumes, and supports sustainable artisanal and semi-industrial production of fermented seasonings in Côte d'Ivoire.
Keywords : *Soumbara*, fermented condiments, alternative legumes, *Bacillus* starter cultures, sensory acceptability, food safety.

INTRODUCTION

Traditional fermented foods play a central role in African diets, contributing simultaneously to food security, cultural identity and the promotion of local biological resources. Initially developed as preservation techniques, fermentation processes are now recognized for their capacity to improve sensory quality, nutritional value and safety of foods through microbial metabolism, including the reduction of antinutritional factors and the production of desirable flavours and bioactive compounds (Parkouda *et al*., 2009; Tamang *et al.*, 2020). In many West African countries, fermented condiments derived from legumes constitute essential dietary components, particularly in contexts where access to animal protein is limited. Among these condiments, *Soumbara*-produced from the alkaline fermentation of *Parkia biglobosa* (African locust bean) seeds is one of the most emblematic. *Soumbara* is widely consumed for its characteristic aroma and strong umami taste, and it represents an affordable source of proteins and lipids. Previous studies have reported protein contents ranging from 30 to 47%, lipid contents between 20 and 43%, and high caloric value, underscoring its nutritional importance (Cissé *et al.*, 2017; Kouamé *et al.*, 2021). However, the sustainability of *Soumbara* production is increasingly threatened by the declining availability of *néré* seeds, a situation attributed to climate variability, deforestation, bush fires and increasing anthropogenic pressure on *P. biglobosa* parklands. This decline raises major concerns for the continuity of traditional production systems and the livelihoods that depend on them. In response to these challenges, alternative legumes such as soybean (*Glycine max*), *Bambara* groundnut (*Vigna subterranea*) and cowpea (*Vigna unguiculata*) have been proposed as potential substitutes for *néré* seeds. These legumes are widely cultivated in West Africa, nutritionally rich and well adapted to local agro-ecological conditions. Their suitability for fermentation has been demonstrated in several studies, which reported acceptable physicochemical and nutritional characteristics of *Soumbara*-type products derived from these substrates (Degnon *et al*., 2020; Akissoé *et al*., 2021; Kouassi *et al.*, 2025). Nevertheless, available data remain fragmented, and comparative evaluations focusing simultaneously on microbiological safety and consumer sensory acceptability are still limited, particularly in Côte d'Ivoire. Furthermore, traditional *Soumbara* production relies mainly on spontaneous fermentation, which is driven by naturally occurring microorganisms, predominantly *Bacillus spp.* Although this process contributes to the development of characteristic sensory attributes, it often leads to variable product quality and may increase the risk of contamination by undesirable microorganisms (Anyogu *et al.*, 2021). Controlled fermentation using selected starter cultures offers a promising alternative, as it allows better control of microbial dynamics, improvement of product safety, and standardization of sensory quality. Species such as *Bacillus subtilis* and *Bacillus velezensis* are known for their strong proteolytic activity and their ability to generate peptides, amino acids and volatile compounds that play a key role in aroma and taste development of alkaline fermented condiments (Rabbee *et al.*, 2019; Fan *et al.*, 2023). Despite these advances, the combined effect of legume blending and starter-guided fermentation on the microbiological quality and sensory acceptability of *Soumbara*-type condiments has not been sufficiently investigated. In particular, there is a lack of data comparing mixed-legume formulations fermented with and without starter cultures to traditional *néré*-based *Soumbara*. Therefore, the present study aimed to evaluate the microbiological quality and sensory characteristics of *Soumbara*-type fermented condiments produced from soybean, *Bambara* groundnut and cowpea

using spontaneous and controlled fermentation processes. It was hypothesized that mixed-legume formulations fermented with selected *Bacillus* starter cultures would yield products with microbiological safety and sensory profiles comparable to those of traditional *néré*-based *Soumbara.* The results are expected to provide scientific evidence supporting the development of sustainable alternatives that reduce dependence on *Parkia biglobosa*, promote locally available legumes, and contribute to food security and resilient agri-food systems in Côte d'Ivoire.

MATERIALS AND METHODS

Plant material: Soybean (*Glycine max* var. Canarana), cowpea (*Vigna unguiculata* var. Touba) and *Bambara* groundnut (*Vigna subterranea*, beige with red mottling morphotype) seeds were obtained from the National Centre for Agronomic Research (CNRA), Bouaké, Côte d'Ivoire. Traditional *Soumbara* produced from *Parkia biglobosa* seeds using local practices was used as a reference sample.

Microbial starter cultures: Two bacterial strains, *Bacillus subtilis* vav15 and *Bacillus velezensis* vav16, previously isolated and characterized in the Microbiology Laboratory of Jean Lorougnon Guédé University (Daloa, Côte d'Ivoire), were used as starter cultures. These strains were selected based on their documented role in alkaline fermentation of legume-based condiments and their enzymatic activities relevant to flavour development (Akanni, 2017; Karamba *et al.*, 2022).

Experimental design and production of fermented condiments : The overall processing steps for the production of the different *Soumbara*-type fermented condiments are summarized in Figure 1, which illustrates the workflows for soybean- and cowpea-based products, *Bambara* groundnut-based products, and the controlled fermentation of the mixed soybean-*Bambara* groundnut formulation. Six *Soumbara*-type fermented condiments were produced and evaluated: traditional *néré*-based *Soumbara* (SN); soybean-based *Soumbara* (SS); *Bambara* groundnut-based *Soumbara* (SP); cowpea-based *Soumbara* (SH); mixed soybean-*Bambara* groundnut *Soumbara* fermented spontaneously (SM); and mixed soybean-*Bambara* groundnut *Soumbara* fermented with starter cultures (ST).

Production of soybean- and cowpea-based *Soumbara* : Soybean and cowpea seeds were processed separately according to the method described by Degnon *et al.* (2020), with minor modifications. Briefly, 500 g of seeds were manually sorted and roasted for 30 min on a hot plate, then crushed while hot. The crushed material was washed to remove seed coats, soaked for 15 min at room temperature, and subjected to two successive cooking cycles of 30 min each with the addition of 750 mL of water per cycle. After draining for 10 min, the cooked seeds were fermented at 37 °C for 48 h. The fermented products were subsequently finely ground and dried for 48 h.

Production of *Bambara* groundnut-based *Soumbara* : *Bambara* groundnut seeds were processed following a protocol adapted from Adebiyi *et al.* (2019). Seeds were sorted, soaked in water for 24 h, manually dehulled and rinsed. The dehulled seeds were then subjected to the same cooking, fermentation (37 °C for 48 h), grinding and drying steps as described for soybean and cowpea.

Production of traditional *néré*-based *Soumbara :* Traditional *Soumbara* from *Parkia biglobosa* seeds was produced according to the method described by Kouamé *et al.* (2021). Briefly, seeds were sorted, washed and pounded with wood ash to remove the first seed coat, followed by drying and winnowing. The partially dehulled seeds were boiled for approximately 12 h to soften the second coat, which was removed by pounding

with sand. After thorough washing, the seeds were boiled again for about 3 h and fermented at approximately 37 °C for 48 h. The fermented product was sun-dried to ensure stabilization.

Controlled fermentation using starter cultures : Starter cultures were stored at −80 °C in Mossel broth supplemented with glycerol and reactivated on Luria–Bertani (LB) agar at 37 °C for 17 h. Each strain was cultured in LB broth at 37 °C for 18–24 h under agitation. Inoculum concentrations were standardized based on optical density and confirmed by plate counting on LB agar after incubation at 37 °C for 24 h. For controlled fermentation, soybean and *Bambara* groundnut matrices were prepared separately as described above, mixed in equal proportions (500 g each) and sterilized at 121 °C for 30 min. The sterile substrates were inoculated with B. subtilis vav15 and B. velezensis vav16 to obtain an initial concentration of approximately 10^5 CFU/g per strain. Fermentation was conducted at 37 °C for 48 h. A control batch fermented spontaneously under identical conditions was prepared in parallel.

Microbiological analyses : Microbiological analyses were carried out prior to sensory evaluation to assess product safety. Aerobic mesophilic bacteria, total coliforms, Enterobacteriaceae, yeasts and moulds were enumerated using appropriate selective media following ISO and AFNOR standard methods. The presence of *Salmonella spp.*, *Staphylococcus aureus* and *Pseudomonas aeruginosa* was investigated using standard detection protocols. Results were expressed as colony-forming units per gram of sample (CFU/g).

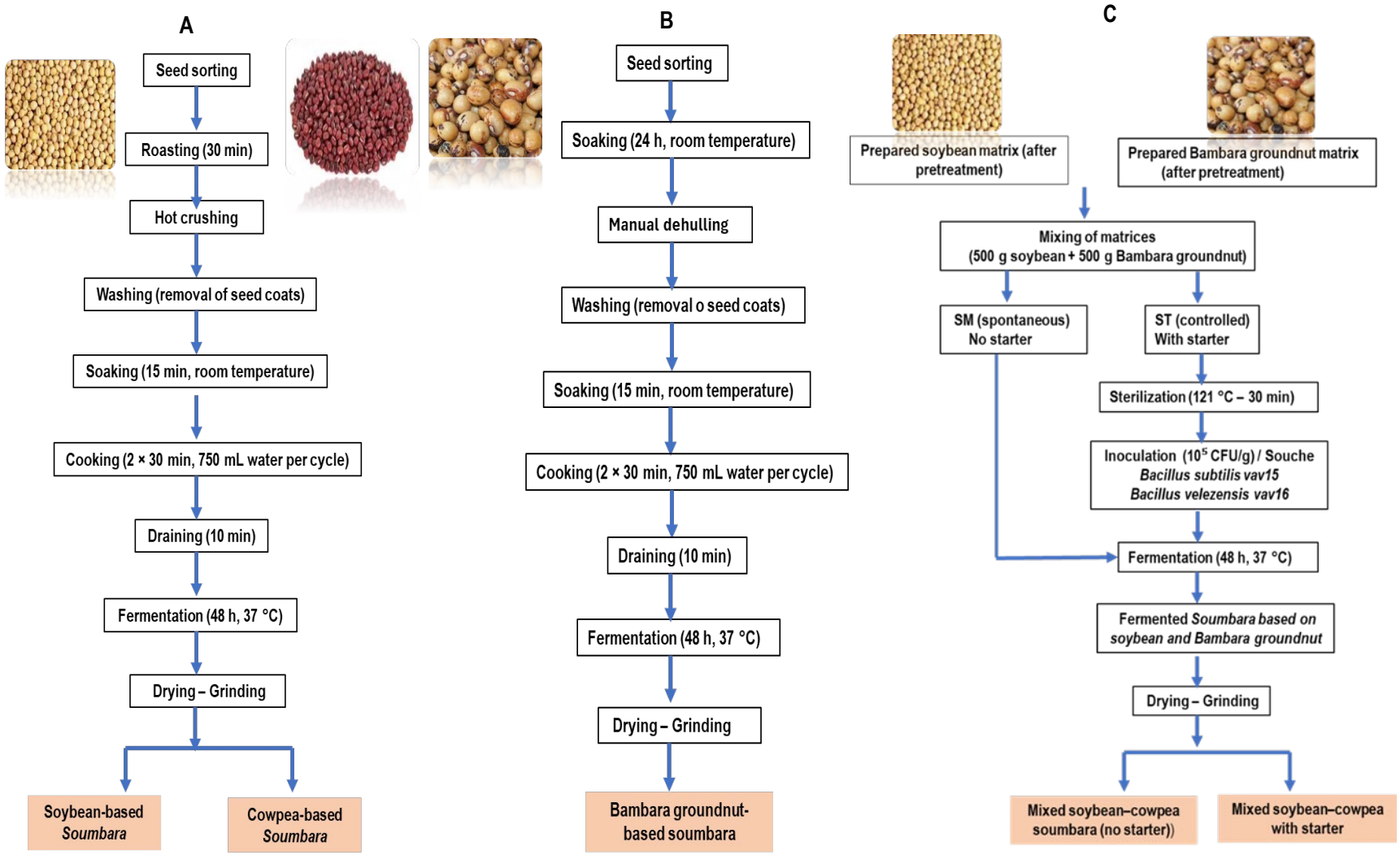

Figure 1 : Production flow diagram of the different fermented condiments.
A: Production flow diagram of soybean- and cowpea-based *Soumbara* ; B: Production flow diagram of *Bambara* groundnut-based *Soumbara*; C: Controlled fermentation process of soybean–*Bambara* groundnut *Soumbara*

Sensory evaluation : Sensory evaluation was conducted on six fermented condiments using 60 untrained consumers aged between 20 and 32 years. Samples were evaluated for appearance, aroma, taste, aftertaste, texture and overall acceptability using a nine-point hedonic scale ranging from 1 (extremely unpleasant) to 9 (extremely pleasant) (Meilgaard *et al.*, 1999). For appearance and aroma evaluation, samples were presented as raw paste (5 g). For taste evaluation, a broth was prepared by boiling 50 g of fermented paste in 450 mL of water for 15 min, and 15 mL portions were served warm. Samples were coded with random three-digit numbers and presented monadically in randomized order. Drinking water and carrot slices were provided between samples to neutralize residual sensation.

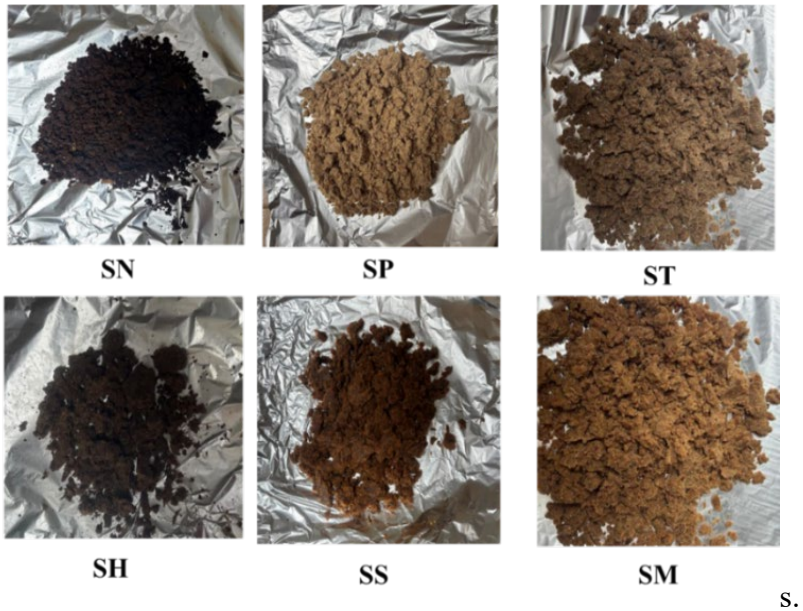

Figure 2: Fermented condiments used for sensory evaluation
SN: Traditional Soumbara produced from néré (Parkia biglobosa) seeds ; SS: Fermented soybean (Glycine max)-based Soumbara; SP: Fermented Bambara groundnut (Vigna subterranea)-based Soumbara; SH: Fermented cowpea (Vigna unguiculata)-based Soumbara; ST: Soybean–Bambara groundnut Soumbara fermented with starter cultures; SM: Soybean–Bambara groundnut Soumbara fermented without starter cultures.

Statistical analysis: All analyses were performed in triplicate. Data were organized using Microsoft Excel 2019 and analysed using R software (version 4.4.3) in the RStudio environment. Results were expressed as mean ± standard deviation. One-way analysis of variance (ANOVA) was used to assess differences among formulations, followed by Tukey's post hoc test at a significance level of $p < 0.05$. Relationships between sensory attributes were explored using Pearson's correlation analysis. Multivariate analyses, including principal component analysis (PCA) and hierarchical clustering, were performed using the FactoMineR, factoextra and corrplot packages.

RESULTS

Microbiological quality of fermented condiments : The microbiological quality of the different *Soumbara*-type fermented condiments is presented in Table 1. Aerobic mesophilic bacteria were detected in all samples, with counts ranging from $2.1 \times 10^3 \pm 0.7$ CFU/g in the *Bambara* groundnut-based formulation (SP) to $6.8 \times 10^3 \pm 0.5$ CFU/g in the mixed soybean-*Bambara* groundnut formulation fermented with starter cultures (ST). These values remained well below the maximum acceptable limit of 10^6 CFU/g for fermented condiments, indicating satisfactory hygienic quality of all products.Total coliform counts ranged from $2.2 \times 10^1 \pm 0.7$ to $5.0 \times 10^1 \pm 1.2$ CFU/g, also below the regulatory threshold of 10^3 CFU/g. Enterobacteriaceae were detected only in the traditional *néré*-based *Soumbara* (SN), while all formulations produced from alternative legumes showed values below the detection limit (< 1 CFU/g). Yeasts and moulds were present at low levels, ranging from 8 ± 2 CFU/g in ST to 78 ± 9 CFU/g in SN. No Salmonella spp., Staphylococcus aureus or Pseudomonas aeruginosa were detected in any of the samples. Overall, all fermented condiments exhibited very satisfactory microbiological quality and complied with current food safety standards.

Hedonic sensory evaluation of fermented condiments: Mean hedonic scores for appearance, aroma, taste, texture, aftertaste and overall acceptability are summarized in Table II. No significant differences were observed among the different formulations for appearance and aroma ($p > 0.05$). In contrast, significant differences were found for taste, texture, aftertaste and overall acceptability ($p < 0.05$). The mixed soybean-*Bambara* groundnut formulation fermented with starter cultures (ST) recorded the highest scores for taste (5.47 ± 1.92), texture (5.40 ± 1.51) and aftertaste (5.71 ± 1.64), values that were not significantly different from those of traditional *néré*-based *Soumbara* (SN). Overall acceptability was highest for SN (5.59 ± 1.96) and ST (5.57 ± 1.63), with no significant difference between these two products. In contrast, formulations based on single legumes, particularly soybean (SS) and cowpea (SH), showed significantly lower overall acceptability scores.

Correlation between sensory attributes and overall acceptability : Pearson's correlation analysis revealed strong positive relationships between overall acceptability and several sensory attributes (Figure 3). Overall acceptability was highly correlated with aroma ($r = 0.99$), texture ($r = 0.94$) and taste ($r = 0.89$), while moderate correlations were observed with appearance ($r = 0.77$) and aftertaste ($r = 0.70$). Strong inter-correlations were also observed among aroma, taste and texture, whereas appearance and aftertaste showed weaker associations.

Table 1 : Microbiological quality of different fermented condiments (CFU/g)

Microbes	**SN**	**SS**	**SH**	**SP**	**SM**	**ST**	**Norm (m)**
Aerobic mesophilic bacteria	$3.2\times10^3 \pm 0.4^a$	$4.5\times10^3 \pm 0.5^b$	$3.5\times10^3 \pm 0.6^a$	$2.1\times10^3 \pm 0.7^c$	$3.2\times10^3 \pm 0.8^a$	$6.8\times10^3 \pm 0.5^d$	10^6
Total Coliforms	$5.0\times10^1 \pm 1.2^a$	$2.3\times10^1 \pm 0.9^b$	$3.5\times10^1 \pm 1.0^b$	$2.6\times10^1 \pm 0.8^b$	$4.0\times10^1 \pm 1.1^a$	$2.2\times10^1 \pm 0.7^b$	10^3
Enterobacteriaceae	$4.0\times10^1 \pm 1.0$	< 1	< 1	< 1	< 1	< 1	10^3
Staphylococcus aureus	< 1	< 1	< 1	< 1	< 1	< 1	10^2
Yeasts and Molds	78 ± 9f	23 ± 3b	37 ± 4c	49 ± 5d	65 ± 6e	8 ± 2a	10^3
Pseudomonas aeruginosa	< 1	< 1	< 1	< 1	< 1	< 1	10^2
Salmonella spp.	0	0	0	0	0	0	Absence
Overall sanitary assessment	QMTS	QMTS	QMTS	QMTS	QMTS	QMTS	—

Values followed by different alphabetical letters within the same row are statistically significantly different (P < 0.05). SN: traditional Soumbara produced from Parkia biglobosa (African locust bean); SS: fermented soybean-based Soumbara (Glycine max); SP: fermented Bambara groundnut-based Soumbara (Vigna subterranea); SH: fermented cowpea-based Soumbara (Vigna unguiculata); ST: mixed soybean–Bambara groundnut Soumbara fermented with starter culture; SM: mixed soybean–Bambara groundnut Soumbara fermented without starter culture; QMTS: very satisfactory microbiological quality.

Table 2 : Hedonic scores of different fermented condiment formulations

Formulation	**Appearance**	**Aroma**	**Taste**	**Texture**	**After taste**	**Overall acceptability**
SS	4.74 ± 2.07^a	4.76 ± 2.19^a	4.33 ± 1.99^b	4.55 ± 2.00^b	4.47 ± 1.97^b	4.53 ± 1.96^b
SN	5.57 ± 1.98^a	5.48 ± 1.87^a	5.03 ± 1.96^{ab}	5.12 ± 1.79^{ab}	5.05 ± 1.92^{ab}	5.59 ± 1.96^a
SP	4.86 ± 2.20^a	4.91 ± 2.12^a	4.26 ± 2.03^b	4.57 ± 2.12^{ab}	4.90 ± 1.86^{ab}	4.90 ± 1.81^{ab}
SM	5.55 ± 1.96^a	5.02 ± 2.13^a	4.71 ± 1.94^{ab}	4.81 ± 2.08^{ab}	4.40 ± 1.96^b	5.00 ± 1.76^{ab}
ST	5.24 ± 2.05^a	5.48 ± 1.85^a	5.47 ± 1.92^a	5.40 ± 1.51^a	5.71 ± 1.64^a	5.57 ± 1.63^a
SH	5.00 ± 1.91^a	4.69 ± 2.16^a	4.02 ± 1.98^b	4.36 ± 1.81^b	4.40 ± 2.04^b	4.52 ± 1.98^b

Values followed by different alphabetical letters within the same column are statistically significantly different ($P < 0.05$). SN: traditional Soumbara produced from Parkia biglobosa (African locust bean); SS: fermented soybean-based Soumbara (Glycine max); SP: fermented Bambara groundnut-based Soumbara (Vigna subterranea); SH: fermented cowpea-based Soumbara (Vigna unguiculata); ST: mixed soybean–Bambara groundnut Soumbara fermented with starter culture; SM: mixed soybean–Bambara groundnut Soumbara fermented without starter culture.

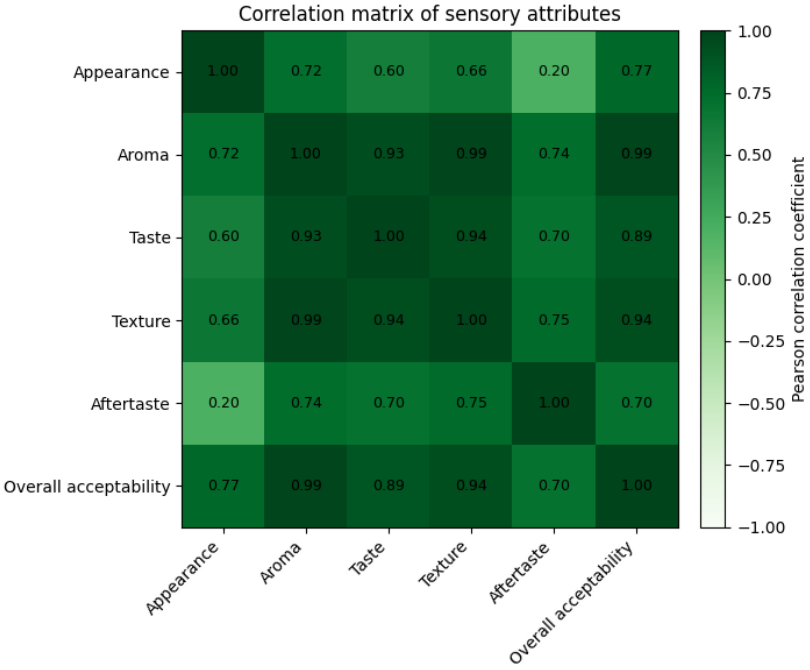

Figure 3 : Correlations between the sensory attributes of fermented condiments

Hierarchical cluster analysis of fermented condiments : Hierarchical cluster analysis based on sensory attributes grouped the fermented *Soumbara* samples into two main clusters (Figure 4). The first cluster comprised traditional *néré*-based *Soumbara* (SN) and the starter-fermented mixed soybean–*Bambara* groundnut formulation (ST), indicating a high degree of sensory similarity between these two products. The second cluster included the remaining formulations (SM, SP, SH and SS), with soybean-, cowpea- and *Bambara* groundnut-based products forming a closely related sub-cluster. The spontaneously fermented mixed-legume formulation (SM) was associated with this group at a higher linkage distance.

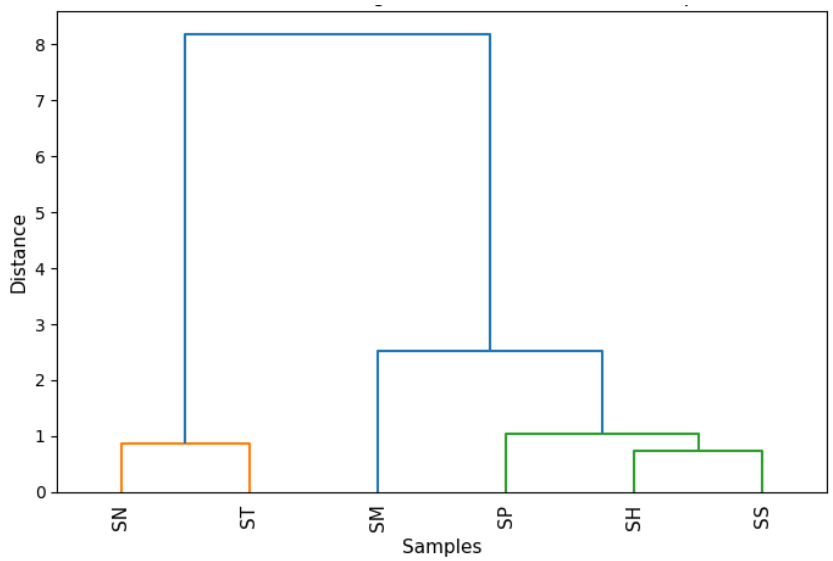

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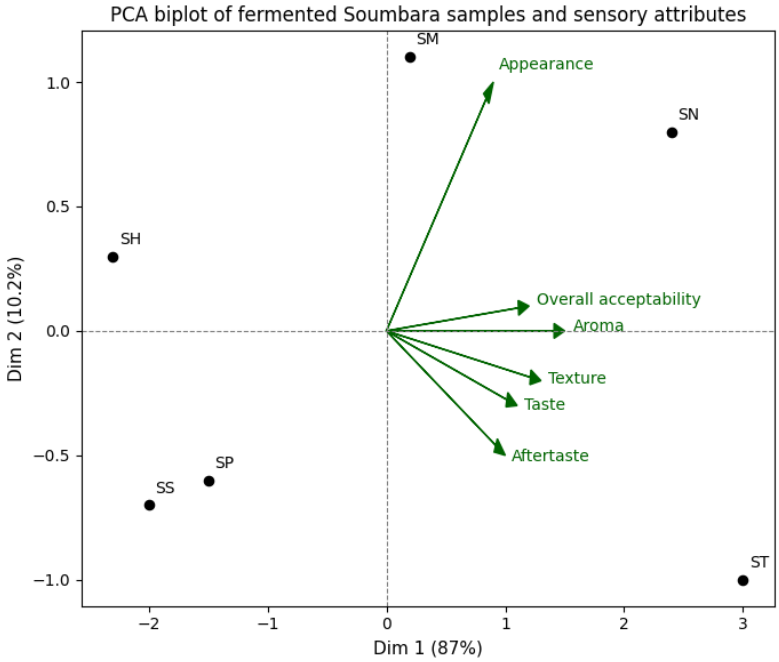
Figure 4 : Hierarchical clustering of fermented *Soumbara* samples

Principal Component Analysis of sensory profiles : Principal component analysis (PCA) performed on the sensory descriptors showed that the first two principal components accounted for 97.2% of the total variance (Figure 5). The PCA biplot highlighted a clear differentiation among the fermented condiments. Samples SN and ST were positioned on the positive side of the first axis, in close association with taste, texture, aroma and overall acceptability. In contrast, formulations SS, SP and SH were located on the negative side of this axis, reflecting lower sensory scores. Along the second axis, the spontaneously fermented mixed-legume formulation (SM) was mainly associated with appearance, while the other samples were clustered near the origin or displayed negative values.



SN: traditional Soumbara produced from Parkia biglobosa (African locust bean); SS: fermented soybean-based Soumbara (Glycine max); SP: fermented Bambara groundnut-based Soumbara (Vigna subterranea); SH: fermented cowpea-based Soumbara (Vigna unguiculata); ST: mixed soybean–Bambara groundnut Soumbara fermented with starter culture; SM: mixed soybean–Bambara groundnut Soumbara fermented without starter culture.

Figure 5 : PCA biplot of fermented *Soumbara* samples and sensory attributes

DISCUSSION

The present study provides a comparative assessment of the microbiological quality and sensory acceptability of *Soumbara*-type fermented condiments produced from alternative legumes using spontaneous and controlled fermentation processes. Overall, the results demonstrate that all formulations exhibited satisfactory sanitary quality, while significant differences were observed in sensory attributes depending on substrate composition and fermentation mode. The low aerobic mesophilic counts recorded in all fermented products indicate good hygienic conditions during processing and effective microbial stabilization during fermentation. Values obtained in this study were well below the commonly accepted threshold of 10^6 CFU/g for fermented condiments and were lower than those reported in previous studies on traditional *Soumbara* and similar alkaline-fermented products marketed in Côte d'Ivoire and neighbouring countries (Fatoumata *et al.,* 2016; Kouamé *et al.*, 2021). The absence of major foodborne pathogens such as Salmonella spp., *Staphylococcus aureus* and *Pseudomonas aeruginosa* further confirms the microbiological safety of the products, highlighting the protective role of alkaline fermentation in inhibiting undesirable microorganisms (Anyogu *et al.*, 2021). The detection of Enterobacteriaceae exclusively in traditional *néré*-based *Soumbara* may be attributed to the strictly artisanal processing conditions under which this product is typically manufactured. Prolonged handling, use of non-sterilized utensils and open-air drying are known to increase the risk of contamination in spontaneous fermentations (Anyogu *et al*., 2021). In contrast, the absence of Enterobacteriaceae in all alternative-legume formulations suggests that improved control of processing steps and the use of starter cultures can significantly enhance the sanitary quality of *Soumbara*-type condiments. Sensory

evaluation revealed that substrate composition and fermentation strategy strongly influenced consumer perception. The mixed soybean-*Bambara* groundnut formulation fermented with starter cultures (ST) achieved sensory scores comparable to those of traditional *Soumbara*, particularly for taste, texture and overall acceptability. This superior performance may be explained by the complementary biochemical properties of the two legumes combined with the metabolic activity of the selected *Bacillus* strains. Soybean provides a protein-rich matrix favourable to extensive proteolysis, while *Bambara* groundnut contributes specific flavour precursors that enhance sensory complexity (Degnon *et al.,* 2020; Kouassi *et al*., 2025). The role of *Bacillus subtilis* and *Bacillus velezensis* as dominant fermentative agents in alkaline legume-based condiments is well documented. These species exhibit strong proteolytic and lipolytic activities, leading to the release of peptides, free amino acids and fatty acids that contribute to umami taste, aroma intensity and characteristic aftertaste (Parkouda *et al.*, 2009; Rabbee *et al.*, 2019; Fan *et al.*, 2023). Controlled fermentation using these starter cultures likely promoted more consistent enzymatic reactions and metabolite production, resulting in improved sensory attributes compared to spontaneously fermented products. Multivariate analyses further supported these observations. The strong correlations between overall acceptability and attributes such as taste, texture and aroma are consistent with previous reports identifying these parameters as key drivers of consumer preference for alkaline fermented condiments (Owusu-Kwarteng *et al.*, 2020; Zhang *et al*., 2022). Hierarchical clustering and PCA clearly grouped the starter-fermented mixed-legume product with traditional *Soumbara*, confirming their sensory proximity and reinforcing the potential of this formulation as a credible alternative. In contrast, formulations based on single legumes, particularly soybean and cowpea, were less appreciated, suggesting that the absence of substrate complementarity may limit flavour development. The intermediate acceptability observed for the spontaneously fermented mixed-legume formulation indicates that legume blending alone is not sufficient to achieve optimal sensory quality, and that controlled fermentation plays a decisive role in shaping consumer perception. Taken together, these findings highlight the importance of combining appropriate raw materials with controlled microbial fermentation to develop safe, acceptable and reproducible *Soumbara*-type condiments. The use of alternative legumes and starter cultures offers a promising pathway to reduce dependence on *Parkia biglobosa* while maintaining the sensory identity of traditional *Soumbara*.

CONCLUSION AND APPLICATION OF RESULTS

This study demonstrated that *Soumbara*-type fermented condiments produced from alternative legumes exhibit satisfactory microbiological quality and comply with food safety requirements. All formulations showed low microbial loads and absence of major foodborne pathogens, confirming the effectiveness of alkaline fermentation in ensuring product safety when appropriate processing conditions are applied. From a sensory perspective, the combination of soybean and *Bambara* groundnut fermented with selected *Bacillus* starter cultures yielded products with sensory profiles comparable to those of traditional *néré*-based *Soumbara*, particularly in terms of taste, texture and overall acceptability. In contrast, formulations based on single legumes or spontaneous fermentation displayed lower consumer appreciation, highlighting the importance of both substrate complementarity and controlled fermentation in shaping desirable sensory

attributes. The application of controlled fermentation using well-characterized *Bacillus subtilis* and *Bacillus velezensis* starter cultures offers a practical strategy to improve product consistency, enhance safety and standardize sensory quality of *Soumbara*-type condiments. These findings provide scientific evidence supporting the promotion of locally available legumes as sustainable alternatives to *Parkia biglobosa*, whose availability is increasingly threatened. Overall, the results contribute to the development of resilient fermented food systems in Côte d'Ivoire by offering viable technological options for reducing dependence on *néré* seeds, supporting artisanal and semi-industrial production, and strengthening food security through diversification of protein-rich fermented condiments.

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