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Organoleptic and microbiological characteristics of cubes of *Irvingia gabonensis* Almonds (Péké)

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The aim of this study was to prepare food cubes using *Irvingia gabonensis* almonds and assess their organoleptic and microbiological quality. *I. gabonensis* almonds and other ingredients sourced from Brazzaville markets were utilized for formulating the stock cubes. Three different formulations were developed based on a mixing plan and subjected to sensory and microbiological evaluation. The results revealed that the formulated stocks were well-accepted by the panelists, with scores of 2.511, 3.128, and 3.468 for the first, second, and third formulations, respectively. Microbiological analysis indicated high satisfactory quality, with the total aerobic mesophilic flora load ranging from 4.9 × 10^3 to 9 × 10^2 CFU/g across the three cube stock samples. Moreover, they were found to be free from thermotolerant and total coliforms, *Staphylococcus aureus*, Salmonella and Shigella, as well as yeasts and molds. This study has facilitated the establishment of a process for producing food-grade stock cubes with favorable organoleptic and hygienic qualities, capable of competing with highly concentrated industrial stock cubes.

Key words: Stock cubes, *Irvingia gabonensis*, organoleptic quality, microbiological quality.

INTRODUCTION

In sub-Saharan Africa, more than two-thirds of the population depends on forests for their livelihoods (CIFOR, 2004). Therefore, non-timber forest products (NTFPs) could play a crucial role in the survival of populations in developing countries, particularly in Central Africa. Non-timber forest products (NTFPs) can be valued based on two contributions: Direct consumption and sale (Awono et al., 2009). Consequently, NTFPs contribute significantly to food security in Central African countries. As highlighted by Mawunu et al. (2016), wild edible NTFPs are primarily exploited for self-consumption. Therefore, NTFPs play a crucial role in the dietary balance, preservation of cultural

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identity, and health of rural populations. Additionally, their commercialization generates income, further enhancing the livelihoods and survival of these communities (Awono et al., 2008).

NTFPs also enrich other foods with additional nutrients. Notably, fruits, almonds, and seeds constitute 45.00% of the most widely consumed NTFPs (Mawunu et al., 2016). In Africa, *Irvingia gabonensis* kernels are extensively consumed, making it one of the most sought-after forest plant species due to its edible seeds (Yao et al., 2023). These kernels serve as flavoring and thickening agents in cooking, often being preserved dry or processed into "cakes" (Ingram et al., 2016). Additionally, dried and ground almonds are utilized to create a sticky, aromatic sauce that enjoys widespread consumption (Adiko-Tapé et al., 2022). Hence, Manirakiza (2007) justifiably asserts that *I. gabonensis* kernels rank among the most consumed NTFPs in Central Africa. Moreover, *I. gabonensis* holds significance as both a food and medicinal plant (Adiko-Tapé et al., 2022).

Despite the benefits of almonds and *I. gabonensis*, they remain traditional condiments in Congo. In the departments of Lékoumou and Sangha, they are often consumed raw as a substitute for okra to thicken sauces or as a replacement for peanut paste to enhance the flavor of foods. Conversely, in places like Côte d'Ivoire, dried and crushed almonds are utilized to create a sticky, aromatic sauce, with the extracted edible oil commonly used in cooking (Adiko-Tapé et al., 2022). However, limited studies have been conducted on processing *I. gabonensis* seeds into stock cubes. Concerning broths, they function as flavor enhancers added to foods to enhance their taste properties (Akpanyung, 2005). Stock cubes have been utilized for a long time across various countries as instant food, with ingredients typically varying based on regional preferences (Al-Subhi, 2013). Therefore, the seeds of *I. gabonensis*, given their ability to enhance the flavor of culinary dishes, present an opportunity to introduce a new brand of stock cubes that can improve the organoleptic quality of Congolese cuisine. Additionally, according to Lobanov et al. (2002), various herbal spices are employed in traditional cooking to enrich food with vitamins, trace elements, and biologically active substances. Hence, this study aims to contribute to food security, promote local foods, and develop new African food products by preparing and evaluating the organoleptic and microbiological characteristics of a stock cube based on *I. gabonensis* almonds.

MATERIALS AND METHODS

The formulation of the stock cubes took place at the Food Technology Laboratory of the National Institute for Research in Engineering Sciences, Innovation, and Technology (INRSIIT). The tasting tests of the dishes prepared with the formulated broth cubes were conducted in the Nzoko district of Brazzaville. Microbiological analyses were performed at the microbiology laboratory of the National Institute for Research in Exact and Natural Sciences (IRSEN). The target population comprised the inhabitants of the city of Brazzaville, specifically those residing in the Nzoko district, who participated in taste tests to assess their preference for stock cubes used in culinary dish preparation. Didactic materials included sensory evaluation sheets with closed questions designed to gather information on the organoleptic quality of the produced stock cubes. The biological materials utilized consisted of *I. gabonensis* almonds, spices, Manihot esculenta crantz leaves, bean seeds, and rice seeds. The samples subjected to analysis comprised dehydrated stock cubes made from *I. gabonensis* almonds.

Media and culture conditions

In this study, a total of eight culture media were utilized. Plate Count Agar (PCA) medium was employed to enumerate the total aerobic mesophilic flora. Chapman's agar was utilized to enumerate bacteria belonging to the species *Staphylococcus aureus*. Purple-pink bile lactose agar was used for the enumeration of fecal and total coliforms. Yeast extract plus chloramphenicol agar was utilized for yeast and mold enumeration. Additionally, bacteria of the genus Salmonella and Shigella were enumerated for presence and absence on Salmonella and Shigella (SS) agar following pre-enrichment in liquid medium and enrichment in Rappoport broth. Inoculations for all pathogens were conducted on the surface and incubated at 37°C for 48 h, except for fecal coliforms, which were incubated at 44°C.

Formulation of bouillon cubes

Parameters studied

The listed parameters that influence the very pleasant taste of the broth cube are the amount of *I. gabonensis* (X1), the amount of spice mixture (X2). These factors have the advantage of being controllable even at the artisanal level.

Mixing plan

Mixing trials are an integral part of the experimental design, particularly in formulating a cube broth through mixing. Mixed designs represent a specialized category of response surface experiments, especially when the product comprises multiple component or elements. Many industrial design and development processes involve formulations or mixtures, where the response is influenced by the proportions of the components present in the mixture. In the simplest form of a mixing experiment, the quality of the product, measured against specific criteria, depends on the relative proportions of the ingredients. In this study, a mixing plan was employed to determine the optimal relative proportions of each ingredient. The mixing plan is presented in Table 1.

Production process of stock cubes from *Irvingia gabonensis* almonds

I. gabonensis almonds sourced from Ouesso (Sangha) and spices were procured at the Ouenzé and Total markets in Brazzaville. Upon arrival at the laboratory, these ingredients underwent sorting and washing with ample water to eliminate as many impurities as possible. Subsequently, the almonds and spices were blanched for 15 min and then dried in an oven at 70°C for 24 h. Following drying, the *I. gabonensis* almonds and dried spices were separately crushed and sieved. Once weighed, the spices were combined to create a spice blend. Upon obtaining the spice mixture, the measurements specified by Minitab were applied. The *I. gabonensis* almond powder,

Table 1. Mixing plan in grams (g).

Formulation	*Irvingia*	Blend	Salt	Egg yolk
1	3.5	6.5	2	4.4
2	3.0	7.0	2	4.4
3	4.0	6.0	2	4.4

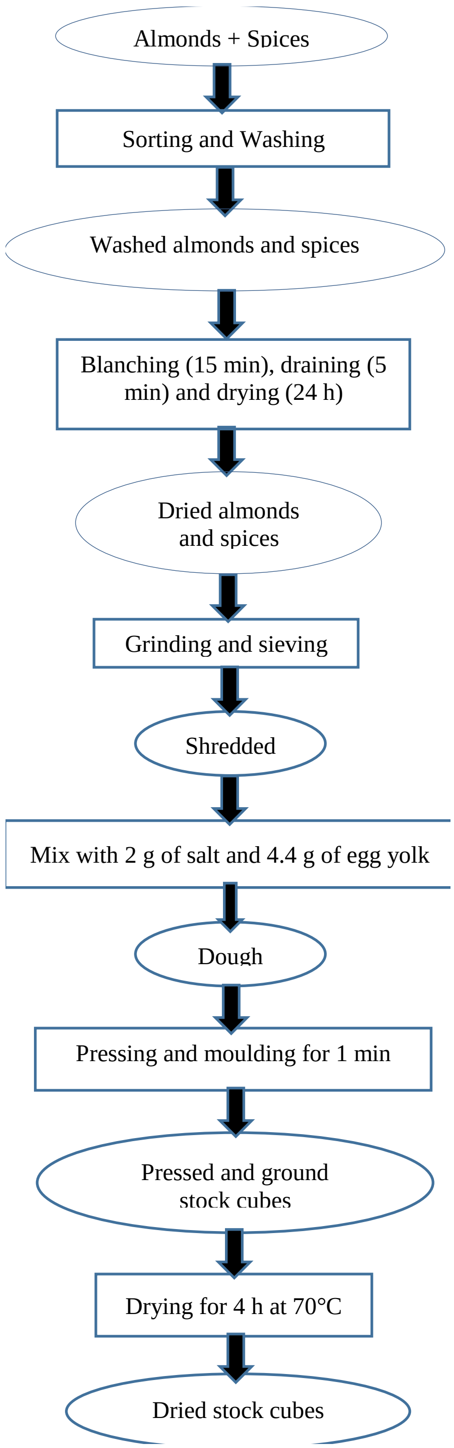

Figure 1. Diagram of the production of *Irvingia gabonensis* stock cubes.

spice mixture, and salt were homogenized with egg yolk. The resulting mixture was shaped into stock cubes and dried in an oven at 70°C for four hours. The manufacturing steps for the stock cubes are depicted in Figure 1. The spice blend utilized for stock cube production comprises 20 g of potato, 2 g of turmeric, 20 g of onion, 40 g of garlic, 12 g of leek, 20 g of parsley, 30 g of celery and 10 g of carrot.

Sensory evaluation of stock cubes formulated with *Irvingia gabonensis* almonds

A hedonic test was conducted to assess the appreciation of *I. gabonensis* almond stock cubes in culinary dishes. Consumers were requested to provide subjective ratings indicating the level of pleasure they experienced from the dishes. The tests were carried out on saka-saka, bean, and rice dishes prepared using the stock cubes. To partake in the sensory evaluation, tasters had to be consumers of saka-saka, beans, or rice. A total of 221 untrained panelists participated in the tasting. The tasters were divided as follows: 81 tasters participated in evaluating the quantity of stock cubes to be utilized in a culinary dish, while 140 tasters assessed the acceptability of different stock cubes used in culinary dishes, comprising 52 for bean dishes, 47 for rice dishes, and 41 for saka-saka dishes. The ratings were scored on a scale of 1 to 4 utilizing a sensory rating sheet, where 1 indicated "I don't like it," 2 represented "I like it a little," 3 denoted "I like it well," and 4 signified "I like it a lot" (Villanueva et al., 2005).

Determining the amount of stock cubes to add to dishes

To determine the amount of stock cube to be incorporated into culinary dishes, three 500 g saka-saka dishes were prepared. 12 g, 18 g, and 24 g of a stock cube of the first formulation were incorporated into the first, second, and third saka-saka dishes, respectively. The three dishes were then boiled for 30 min. Finally, the three saka-saka dishes were subjected to a hedonic test to determine the ideal amount to incorporate into the culinary preparations.

Preparation of culinary dishes for sensory analysis

Three culinary dishes were prepared for the hedonic tests. These included saka-saka, bean and rice dishes, which have the advantage of being frequently consumed by the Congolese, to which we added the formulated stock cubes in order to assess their appreciation by consumers.

Preparation of the different saka-saka dishes

The leaves of *Manihot Esculenta Crantz* were purchased at the market in Brazzaville and crushed using a mortar. Subsequently, 2 kg of these crushed leaves were combined with 30 g of salt in a pot containing 4.5 L of water. The mixture was then boiled on a hot plate until it reached a boiling point. After cooking, 250 mL of oil was introduced into the pot and heated for 10 min. The prepared leaves were then divided into three 500 g portions. Subsequently, 18 g of stock cube from each formulation was added to each dish. Finally, the dishes were boiled for 30 min.

The leaves of Manihot Esculenta Crantz were purchased at the market in Brazzaville and crushed using a mortar. Subsequently, 2 kg of these crushed leaves were combined with 30 g of salt in a pot containing 4.5 L of water. The mixture was then boiled on a hot plate until it reached a boiling point. After cooking, 250 mL of oil was introduced into the pot and heated for 10 minutes. The prepared leaves were then divided into three (3) 500 g portions. Subsequently, 18 g of stock cube from each formulation was added to each dish. Finally, the dishes were boiled for 30 min.

Preparation of the different bean dishes

The sorted beans were washed in water. 2 kg of the washed beans were boiled over a fire until cooked, and 10 g of salt and the entire capacity of the canned tomato were added to the pot containing the beans, which was then heated for 15 min. The beans were divided into three 500 g dishes, each containing 18 g of a stock cube of each formulation. Finally, the three dishes were cooked for about 15 min.

Preparation of rice dishes

Three 500 g dishes of white rice were prepared, each containing 18 g of stock cube of each formulation. Then 70 mL of oil and 5 g of salt were added and the whole was cooked.

Consumer-oriented test procedure

During each tasting session, tasters were provided with a plate, a spoon, and a glass of water for rinsing. Each taster approached the buffet and received a spoonful of the dish to sample. Following the tasting, tasters were asked to respond to a series of questions to express their impressions. After tasting each dish, tasters rinsed their mouths with mineral water to cleanse their taste buds (Boutrolle, 2007). Throughout the session, two evaluations were conducted: assessment of the taster's behavior during the tasting and the ratings provided afterward. Tasters whose ratings aligned with their facial expressions were retained. For instance, if a taster expressed genuine liking for the dish after consuming the entire sample, or alternatively, if they spat out the sample and then expressed dislike for the dish, their response was considered. Conversely, a taster who spat out the sample but claimed to like the dish afterward was not considered. Hence, the reliability of this method was ensured.

Microbiological analysis

Sampling procedure

The stock cube samples to be analyzed were prepared at the INRSIIT Agrifood Technology Laboratory. The stock cubes were wrapped in aluminum foil and transported to the microbiological analysis laboratory in a carefully pre-washed, hermetically sealed jar.

Preparation of culture media

Preparation of inocula and inoculation (NF EN ISO 6887-1)

The sample to be analyzed is homogenized using a spatula sterilized by Bunsen burner flame. This is done in order to mix the surface and deep parts of the stock cubes. Then, using a precision balance (G&G Electronic scal, max=500 g, d=0.1), 10 g were removed with the spatula under aseptic conditions. This mass was aseptically transferred to a bottle containing 90 mL of sterile physiological water. The mixture was homogenized by manual shaking for approximately two minutes and represents the stock solution diluted to 10^{-1}. Then, decimal dilutions ranging from 10^{-1} à 10^{-5} were prepared from the stock solution. Briefly, 1 mL of the stock solution was withdrawn with a pipette and transferred to a test tube containing 9 mL of sterile physiological water. After manual homogenization, the procedure was repeated to inoculate the second test tube. And so on until dilution 10^{-5}. All of these dilutions constitute the inocula for inoculation.

Finally, a 100 µL volume of each dilution was taken with a pipette and inoculated onto the surface of the corresponding agar medium poured into Petri dishes. The inoculated cultures were incubated for 24 to 48 h. After incubation, plates containing fewer than 300 colonies were selected for manual colony counting. Two Petri dishes were inoculated per dilution. The number of microorganisms (N) per gram of product sample was calculated using the following formula:

$$N=\frac{n}{V_{I.D}} \times \frac{V_{SM}}{V_M}$$

N= Bacterial count CFU/g, n= Colony average of the dilution taken into account, V_I= inoculum volume, D= dilution factor
V_{SM}= stock solution volume, V_M= Mass of the sample.

Enumeration of microorganisms

Total aerobic mesophilic flora (NF. V 08-051-Feb.1999)

Inoculation was performed on the surface by placing 100 µL of suspension from each dilution tube 10^{-1} to 10^{-5} on PCA medium. Next, the inoculum was spread in the sterile zone of the Bunsen burner (10 cm) using a Pasteur pipette converted into a spreader. Finally, the agar plates were incubated in a drying oven (DHP-9052) at 37°C for 48 h with the lid facing up. All colonies were counted.

Dénombrement des coliformes fécaux (thermo- tolérants) et totaux (NFV08-060-mars 1996)

Total and fecal coliform counts were performed on VRBLA (crystal violet, neutral red, bile, lactose and agar) agar medium. Surface inoculation was performed by plating 100 µL of dilutions of $10^{-1}, 10^{-3}$ and 10^{-5} separately on VRBLA agar. After inoculation, the cultures were incubated for total and fecal coliform enumeration at 37 and 44°C, respectively, for 24 to 48 h. Colonies counted must be dark red with a diameter greater than or equal to 0.5 mm.

Enumeration of suspected pathogenic staphylococci (*Staphylococcus aureus*) (NFV 057-1-nov.1994)

Chapman's medium poured into Petri dishes was surface inoculated by spreading 100 µL dilutions of $10^{-1}, 10^{-3}$ and 10^{-5} separately. Incubation was performed at 37°C for 24 to 48 h. A first reading was made after 24 h and a second reading was made after 48 h of incubation. Only yellow colonies are considered to be *S. aureus*.

Enumeration of Salmonella and Shigella (NF EN ISO 6579-1, 2017)

Salmonella testing was performed as follows.

Pre-enrichment culture

A 25 g of stock cubes was weighed and inoculated into 100 mL of preenrichment medium. This solution was incubated for 24 hours for non-selective enrichment.

Enrichment

Enrichment is performed on Rappoport Vassiliadis (RV) selective enrichment medium. One ml of pre-enriched solution was inoculated into Rappoport medium. The mixture was then incubated at 37°C for 24 h.

(a): Stock cubes 1 of *I. gabonensis* **(b): Stock cubes 2 of *I. gabonensis*** **(c): Stock cubes 3 of *I. gabonensis***

Figure 2. Stock cubes of *Irvingia gabonensis.*

Isolation

Salmonella and Shigella were isolated on selective SS agar. The platinum loop or Pasteur pipette was immersed in the enrichment medium. The suspension attached to the loop was then spread by the dial method. The plates were incubated at 37°C for 24 h. Shigella colonies to be counted should be colorless, while Salmonella colonies to be considered should have a black center.

Counting of the fungal flora: yeasts and molds

The fungal flora was enumerated on chloramphenicol agar. After solidification, plates were inoculated separately with 100 µL dilutions of $10^{-1}, 10^{-3}$ and 10^{-5} on the surface and then incubated at 37°C for 3 to 4 days. Plates containing less than 150 colonies after 4 days of incubation are retained for enumeration**.**

Data processing and analysis

Epi-Info 6.fr, Word and Minitab 20 were used to process the data collected and to prepare the raw tables. Averages were calculated based on the scores assigned to each stock cube. The perceived significant difference between two percentages was verified using standard tests of difference statistics. The Student's t-test (1995) was used to compare more than two percentages, and the Tukey test was used to compare two means, with a significance threshold of 5%.

The mean ratings of the stock cubes given by the tasters were compared by analysis of variance (ANOVA) at the 5% α level of significance.

Two hypotheses were used in this analysis:

Null hypothesis: The parameter does not differ between the different types of broth if and only if P is greater than 5 %;
Alternative hypothesis: The parameters of the different types of bouillon cubes are different if P is less than 5 %.

RESULTS

Formulated bouillon cubes obtained

The mixing scheme resulted in three formulated broth cubes (Figure 2). The formulated bouillon cubes are green with a yellow tint, have a crumbly consistency, and a characteristic taste and odor.

Quantity of stock cubes to be added to a dish

Appendix Table 1 presents the findings from the evaluation of the quantity of stock cube to be incorporated into a culinary dish. Appendix Table 2 indicates that tasters preferred the saka-saka dish containing 18 g of bouillon cubes from the first formulation compared to the saka-saka dishes containing 12 g and 24 g of bouillon cubes from the same formulation, respectively.

Statistical analysis reveals a p-value of less than 0.05, indicating a significant difference between the values. Consequently, for the remainder of the experiment, the amount of stock cube added to a culinary dish was set to 18 g. The results of this experiment are detailed in Appendix Table 1.

Consumer-oriented tests

Tasting of bean dishes

Appendix Table 3 displays the outcomes of the sensory evaluation of bean dishes with bouillon cubes, categorized by formulation type. In the case of the bean dish with bouillon cubes from the first formulation, 48.1% of tasters expressed a strong preference, while 23.1% indicated moderate liking, and 7.7% reported dislike. Additionally, the dish received an average score of 3.115 out of 4, indicating overall appreciation. The statistical analysis revealed a significant difference in scores ($p < 0.05$). Moving on to the bean dish with bouillon cubes from the second formulation, 48.1% of tasters expressed strong liking, with 23.1 and 19.2% indicating moderate and slight preference, respectively, while 9.6% expressed dislike. Statistical analysis suggests that the second formulation cube enhances organoleptic quality significantly. Similarly, for the bean dish prepared with bouillon cubes from the third formulation, 48.1% of tasters favored it strongly, 25.0% moderately, and 19.2% slightly, while 7.7% expressed dislike, with a highly significant difference observed ($p < 0.05$). However, for the dish prepared with the Adja cube (control), 28.8% of tasters strongly preferred it, while 25.0% expressed moderate liking, and others expressed mixed preferences. The statistical analysis indicated a highly significant difference ($p < 0.05$).

Tasting of rice dishes

Appendix Table 4 illustrates the outcomes of the sensory evaluation of rice dishes prepared with various cube broth formulations. For the rice dish with the first formulation, 44.7% of tasters expressed little liking, while 27.7% indicated moderate preference, and 10.6% reported dislike. The difference was found to be highly significant ($p < 0.05$). Moving on to the rice dish with the second formulation, 42.6% of tasters strongly favored it, with 31.9% indicating moderate liking, and 4.3% expressing dislike. Statistical analysis revealed a highly significant difference ($p < 0.05$), indicating that Bouillon Cube 2 enhances the organoleptic quality of rice and is well-received by consumers, with an average score of 3.128 out of 4. Similarly, for the rice dish with the third formulation, 61.7% of tasters expressed strong liking, followed by 27.7% indicating moderate preference, and 4.3% reporting dislike, with a highly significant difference observed ($p < 0.05$). The stock cube from the third formulation significantly improves the organoleptic quality of rice and is highly appreciated by consumers, with an average score of 3.468 out of 4. Regarding the rice dish prepared with the Adja cube, the results indicate that 38.3% of tasters strongly preferred it, followed by 34.0% expressing slight liking. Statistical analysis showed that the Adja Stock cube received an average score of 2.872 out of 4, with a significant difference between the percentages observed ($p < 0.05$).

Tasting of Saka-Saka dishes

Appendix Table 5 presents the outcomes of the sensory evaluation of saka-saka dishes prepared with different stock cube formulations. For the saka-saka dish with the first stock cube formulation, 36.6% of tasters expressed dislike, while 26.7% indicated slight liking. Overall, this dish received a score of 2.220 out of 4, with a significant difference observed between the percentages ($p < 0.05$). Moving on to the saka-saka dishes prepared with the second formulation stock cube, 34.1% of tasters strongly preferred it, followed by 28.8% expressing slight liking. This dish received an overall score of 2.634 out of 4, indicating a moderate improvement in the organoleptic quality, with a significant difference observed ($p < 0.05$). Conversely, for saka-saka dishes prepared with stock cube 3, 53.7% of consumers strongly favored them, with 26.8% indicating moderate preference. This stock cube received an average score of 3.268 out of 4, significantly enhancing the organoleptic quality of saka-saka dishes, with a significant difference observed between the percentages ($p < 0.05$). Regarding the dish prepared with the Adja cube, 41.5% of consumers strongly preferred it, followed by 26.8% indicating moderate liking. The Adja cube received a score of 2.878, with a significant difference observed between the percentages ($p < 0.05$).

Classification of stock cubes by comparison of multiple means using tukey's test

The broth cube classification results depicted in Figure 3 and Table 2 indicate that stock cube 3 holds the top position with a mean score of 3.290, followed by cube broth 2 with a mean score of 2.953, and cube broth Adja with a mean score of 2.775. The first broth cube ranks lowest with a mean score of 2.615. Stock cube 3 appears to be the most favored choice across bean, rice, and saka-saka dishes.

Analysis of Variance (ANOVA)

The analysis of variance shows that the p-value is greater than 0.05. This means that there is no significant difference between the stock dice.

Microbiological quality

Total Aerobic Mesophilic Flora (FMAT)

Figure 4 shows the FMAT loading of the three broth cube samples. Samples F1, F2 and F3 have 7.7. 10^3, 4.9 .10^3 and 9.102 CFU/g sample respectively. However, these values are below the limit set by the Senegalese standard, which is 10^5 CFU/g.

Thermotolerant and total coliforms

The three stock cube samples analyzed were free of fecal coliforms and total coliforms. They are therefore in compliance with the standard (NS 03-146), which sets the compliance threshold for fecal coliforms and total coliforms at 10^2 CFU/g.

Staphylococcus aureus

Samples F1, F2 and F3 were free of any contamination by *S. aureus* species. Since the threshold value set by the Senegalese standard is 10^3 CFU/g, these samples meet the standard for this parameter.

Salmonella and Shigella

The results show that none of the three stock cube

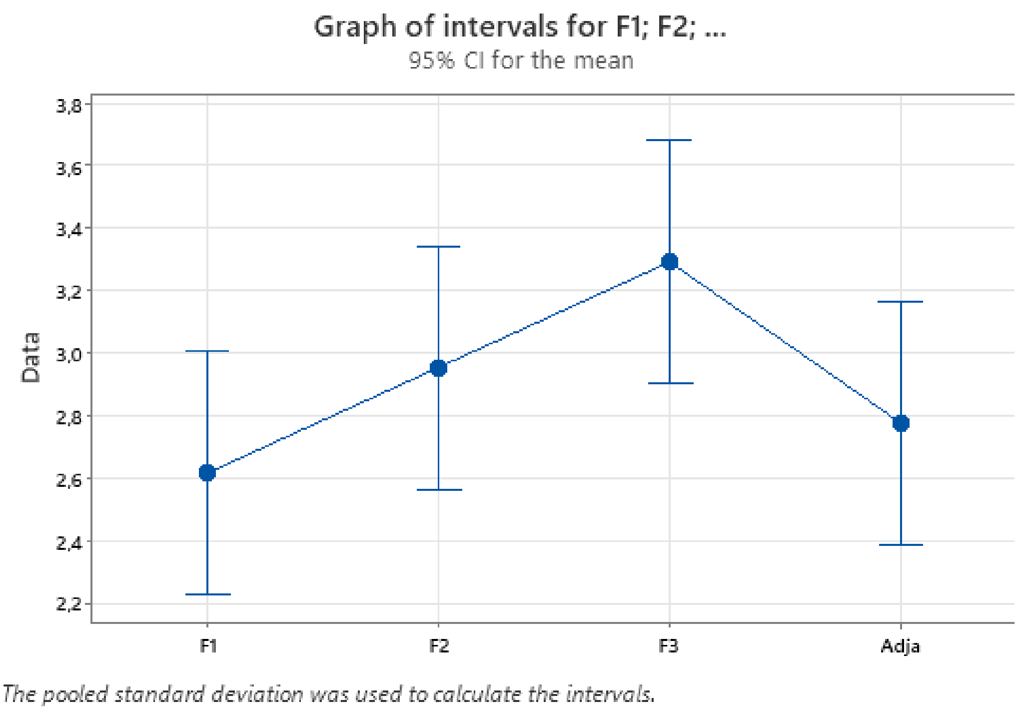

Figure 3. Graph of cube broth intervals.

Table 2. Analysis of Variance (ANOVA) of average dish ratings.

Origin	DL	SomCar ajust	CM ajust	F-value	p-value
Factor	3	0.7540	0.25134	2.93	0.099
Error	8	0.6851	0.08564		
Total	11	1.4391			

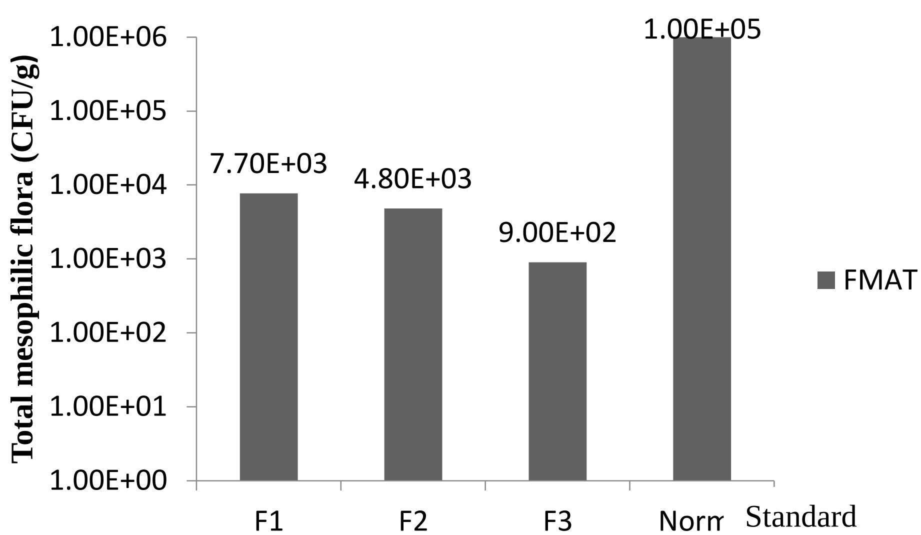

Figure 4. FMAT load of the three analyzed cube samples.

samples analyzed contained Salmonella or Sheguella. These results are in line with Senegalese standards.

Yeasts and molds

All three stock cube samples were free of fungi, that is, yeasts and molds. In fact, no colonies of these microorganisms were observed. The Senegalese standard sets the threshold at 10^3 CFU/g, which confirms the conformity of these samples.

DISCUSSION

The formulation results revealed three dehydrated stock cubes formulated with *I. gabonensis* seeds. Sensory analysis results of rice prepared with *I. gabonensis* seed cubes indicated acceptability for all three formulations. Mean values obtained in the acceptability test for each formulation were above the midpoint (2) of the hedonic scale, which ranged from 1 to 4: 2.511 for formulation 1, 3.128 for formulation 2, and 3.468 for formulation 3. Our findings are in line with those of Rodrigues et al. (2016), who conducted a study on the development of stock cubes from souari nut pulp: formulation, physicochemical, and sensory evaluation. Their sensory analysis of rice prepared with souari stock cubes demonstrated that all three formulations were promising, with mean values obtained in the acceptability test for each formulation exceeding the midpoint (2.5) of the hedonic scale, which ranges from 1 to 5. This could be attributed to the spices' intended purpose of seasoning, flavoring, preserving, and coloring while imparting specific taste (Annou, 2017).

Moreover, our stock cubes formulated with *I. gabonensis* seeds colored rice or sauces yellow, similar to souari stock cubes by the same authors (Rodrigues et al., 2016), which also colored rice yellow. These results may be attributed to the presence of turmeric in *I. gabonensis* stock cubes. Turmeric, known as a natural colorant, is widely used to color sauces, imparting a yellow hue due to the presence of curcumin (Jourdan, 2015). According to Hombourger (2010), turmeric serves as both a spice and a colorant for various foods.

However, the results of sensory analysis revealed that the stock cubes of the third and second formulations were much more appreciated compared to the Adja stock cube. This demonstrates that our stock cubes formulated with *I. gabonensis* almonds are accepted by consumers and can compete with industrial stock cubes sold in the markets. Our findings contrast with those of Masseri et al. (2021), who found that during sensory analyses, control stock cubes sold in the markets received more appreciation in terms of taste and overall appreciation compared to the formulated stock cubes with spices. This disparity could be attributed either to the quality of the raw materials or to the method used to formulate the stock cubes. As highlighted by Meilgaard et al. (2006), the aroma, flavor, and color of foods generally depend on the method of food processing, whereby the quality of the raw material and the processing method determine the quality of the product. Additionally, our results align with those of Ismail and Sahibon (2018), who reported that their stock cubes prepared with the addition of sea bream (Nemipterus japonicas) hydrolysate were appreciated by the panelists.

The results of the microbiological analyses of the *I. gabonensis* almond cubes indicate that they are free of pathogenic microorganisms that could pose a health risk to consumers. Analysis of the total aerobic mesophilic flora revealed that samples F1, F2, and F3 had $7.7.10^3$, $4.9.10^3$, and 9.10^2 CFU/g of sample, respectively. However, these values are lower than the limit set by the Senegalese standard, which is 10^5 CFU/g. Our values are lower than those found by Kambire et al. (2021), who, during a study on the microbiological and physicochemical characteristics of three types of "soumbara" from African carob seeds in Korhogo markets, Ivory Coast, reported that the loads of mesophilic aerobic germs in the different types of "soumbara" varied from 6.17 to 8.38 $\log_{10}$ CFU/g and were between 6.41 and 8.38 log10 CFU/g for granulated "Soumbara", 6.94 and 7.74 $\log_{10}$ CFU/g for "Soumbara" in powder, and between 6.17 and 8.74 $\log_{10}$ CFU/g for "Soumbara" in paste. The hygienic quality of *I. gabonensis* cubes is superior to that of soumbara. This difference could be explained by the fact that Sumbala is sold without packaging and undergoes fermentation during production.

The analysis of thermotolerant and total coliforms, *S. aureus*, Salmonella and Shigella, and yeasts and molds showed that the stock cubes prepared from *I. gabonensis* are free of coliforms, *S. aureus*, Salmonella and Shigella, and yeasts and molds. These results are in accordance with the standard. This can be attributed to good hygiene practices during production. Vegetables are often implicated in cases of food poisoning (Belomaria et al., 2007), and the fact that our stock cubes with spices sold in the market are free of pathogenic microorganisms indicates that they have been eliminated during washing and bleaching. These findings are consistent with the report of Ademola et al. (2013), who suggest that the addition of salt, a natural food preservative, slows microbial growth and extends the shelf life of stock cubes. Therefore, the addition of salt to *I. gabonensis* stock cubes would promote preservation and inhibit microbial growth.

The absence of pathogenic microorganisms in the formulated *I. gabonensis* almond cube broths can also be attributed to the presence of certain spices with antibacterial activity. For example, garlic and turmeric are potent antioxidants due to the cocktail of substances they contain, such as tocopherols, steroids, flavonoids, and vitamins C, B6, K, and E, as well as a small amount of β-carotene (Keith, 2006). Celery and parsley are rich in antibacterial properties (Keith, 2006), while onion (*Allium cepa* L.) is an exceptional source of flavonols (Makris and Rossiter, 2001). Additionally, the dehydration process of the stock cubes prevents bacterial proliferation.

Our results surpass those found by Kambire et al. (2021), Somda et al. (2014), who reported 1.71 and 2.25, 1.86 and 2.96, and 1.13 and 1.64 log10 CFU/g for granulated, powder, and paste types, respectively, and 2.13 log10 (CFU/g) ± 0.06 of total coliforms in sumbala. Regarding the analysis of Staphylococcus aureus, our results are superior to those of Degnon et al. (2020), who found values ranging from 190 to 250 CFU/g in Afitin, and those of Somda et al. (2014), who found values ranging from 2.51 to 4.58 log^{10} CFU/g in sumbala samples. Furthermore, our results align with those of Akintade et al. (2022), who did not observe Staphylococcus spp. in pumpkin broth cubes. Our results on mold analysis are similar to those of Degnon et al. (2020), who found no mold load in Afitin, and to those of Dossou et al. (2008), who demonstrated during microbiological analyses of different types of seasoning broths based on improved Lanhouin that their microbiological results met the standard. However, our results surpass those of Degnon et al. (2020) regarding yeast analysis, as these authors found values ranging from 24 to 90.10^3 CFU/g in three samples of Afitin. This difference could be explained by the fact that Afitin undergoes fermentation during its production.

Conclusion

The formulation of stock cubes based on *I. gabonensis* almonds, implemented through a mixing plan, resulted in the production of broths that met microbiological standards. These broths received positive organoleptic evaluations across various culinary dishes and outperformed the Adja stock cube, an imported product commonly consumed in Congo and used as a control in this study. These findings are pertinent in the context of designing food flavor and aroma enhancers utilizing locally available resources.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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APPENDICES

Appendix Table 1. Estimating the amount of stock cube to be added to a dish.

Parameter	Workforce	Percent	95% Confidence Intervals (%)	Statistical values
Saka-saka dish with 12 g of F1 stock cube	25	30.9	21.1 % - 42.1	χ^2= 25.061
Saka-saka dish with 18 g of F1 stock	44	54.3	42.9 % - 65.4	ddl = 80
Saka-saka dish with 24 g of F1 stock	12	14.8	7.9 % - 24.4	p= 0.000
Total	81	100		

χ^2= chi-squared; ddl= degrees of freedom; p= p-value; F1= first formulation.

Appendix Table 2. Acceptability of bean dishes prepared with stock cubes.

Type of stock cube	Parameter	Workforce	Percent	95% Confidence intervals (%)	Statistical values
	I don't like it	4	7.7	2.1 - 18.5	χ^2= 22.398
	I like it a little	11	21.2	11.1 - 34.7	ddl = 51
1st formulation	I like it well	12	23.1	12.5 - 36.8	M= 3.115 ± 1.003
	I like it a lot	25	48.1	34.0 - 62.4	p= 0.000
	Total	52	100		
	I don't like it	5	9.6	3.2 - 21.0	χ^2= 21.594
	I like it a little	10	19.2	9.6 - 32.5	ddl = 51
2nd formulation	I like it well	12	23.1	12.5 - 36.8	M= 3.096 ± 1.034
	I like it a lot	25	48.1	34.0 - 62.4	p= 0.000
	Total	52	100		
	I don't like it	4	7.7	2.1 - 18.5	χ^2= 22.816
	I like it a little	10	19.2	9.6 - 32.5	ddl = 51
3rd formulation	I like it well	13	25.0	14.0- 38.9	M= 3.135 ± 0.991
	I like it a lot	25	48.1	34.0 - 62.4	p= 0.000
	Total	52	100		
	I don't like it	13	25.0	14.0 - 38.9	χ^2= 16.012
	I like it a little	11	21.2	11.1 - 34.7	ddl = 51
Cube Adja	I like it well	13	25.0	14.0- 38.9	M= 2.577 ±1.161
(Witness)	I like it a lot	15	28.8	17.1- 43.1	p= 0.000
	Total	52	100		

Appendix Table 3. Acceptabilité du plat de riz préparé avec les bouillons cube.

Type of stock cube	Parameter	Workforce	Percent	95% Confidence interval (%)	Statistical Values
	I don't like it	5	10.6	3.5 - 23.1	χ^2= 19.001
	I like it a little	21	44.7	30.2 - 59.9	ddl = 46
1st formulation	I like it well	13	27.7	15.6 - 42.6	M= 2.511 ± 0.906
	I like it a lot	8	17.0	7.6 - 30.8	p= 0.000
	Total	47	100		
	I don't like it	2	4.3	0.5 - 14.5	χ^2= 23.833
	I like it a little	10	21.3	10.7 - 35.7	ddl = 46
2nd formulation	I like it well	15	31.9	19.1 - 47.1	M= 3.128 ± 0.900
	I like it a lot	20	42.6	28.3 - 57.8	p= 0.000
	Total	47	100		

Appendix Table 3. Contd.

3rd formulation	I don't like it	2	4.3	0.5 - 14.5	χ²= 29.589
	I like it a little	3	6.4	1.3 - 17.5	ddl = 46
	I like it well	13	27.7	15.6- 42.6	M= 3.468 ± 0.804
	I like it a lot	29	61.7	46.4 - 75.5	p= 0.000
	Total	47	100		
Cube Adja (Witness)	I don't like it	4	8.5	2.4 - 20.4	χ²= 19.034
	I like it a little	16	34.0	20.9 - 49.3	ddl = 46
	I like it well	9	19.1	9.1 - 33.3	M= 2.872 ± 1.035
	I like it a lot	18	38.3	24.5 - 53.6	p= 0.000
	Total	47	100		

Appendix Table 4. Acceptability of Saka Saka dish prepared with stock cubes.

Type of stock cube	Parameter	Workforce	Percent	95% confidence intervals	Statistical values
1st formulation	I don't like it	15	36.6	22.1 - 53.1	χ²= 12.117
	I like it a little	11	26.8	14.2 - 42.9	ddl = 40
	I like it well	6	14.6	5.6 - 29.2	M= 2.220 ± 1.173
	I like it a lot	9	22.0	10.6 - 37.6	p= 0.000
	Total	41	100		
2nd formulation	I don't like it	9	22.0	10.6 - 37.6	χ²= 14.318
	I like it a little	11	26.8	14.2 - 42.9	ddl = 40
	I like it well	7	17.1	7.2 - 32.1	M= 2.634 ± 1.178
	I like it a lot	14	34.1	20.1 - 50.6	p= 0.000
	Total	41	100		
3rd formulation	I don't like it	3	7.3	1.5 - 19.9	χ²= 22.044
	I like it a little	5	12.2	4.1 - 26.2	ddl = 40
	I like it well	11	26.8	14.2 - 42.9	M= 3.268 ± 0.949
	I like it a lot	22	53.7	37.4 – 69.3	p= 0.000
	Total	41	100		
Cube Adja (Witness)	I don't like it	9	22.0	10.6 – 37.6	χ²= 15.521
	I like it a little	4	9.8	2.7 - 23.1	ddl = 40
	I like it well	11	26.8	14.2 - 42.9	M= 2.878 ± 1.187
	I like it a lot	17	41.5	26.3 - 57.9	p= 0.000
	Total	41	100		

Appendix Table 5. Classification of Stock Cubes by Tukey's Method.

Postman	N	Mean
F3	**3**	**3.290**
F2	**3**	**2.953**
Adja	**3**	**2.775**
F1	**3**	**2.615**