EFFECTS OF TWO MODES OF TECHNOLOGICAL TREATMENTS ON THE PROXIMAL COMPOSITION AND SENSORY ACCEPTABILITY OF MILLET(*Pennisetum glaucum* L. R. Br.) AND TIGER NUTS (*Cyperus esculentus* L.), BASED COOKIES- TYPE FOODS ENRICHED WITH PROBIOTICS.

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Abstract

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Background. The application of appropriate biotechnology to the combination of millet and tiger nuts could contribute to the nutritional and sensory improvement of the products of their transformation into cookies type foods. **Methods.** Foods made from roasted composite flour and steamed composite lumps were fermented by a probiotic leaven. The proximal composition of the products was determined using standardized analytical methods.**Results.**The roasted composite flour feed had the highest protein, water and ash content compared to the steamed composite lumps. It also achieved a higher acceptability rate. **Conclusion.** This study highlights the interest of biotechnologies for the development of local resources and opens prospects for the development of innovative and more competitive food products.

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Introduction

The main purpose of technological treatments is to improve the nutritional, sensory and health quality of food, but also its conservation and its food or commercial use, outside the places and periods of production (Jeantet, 2016). Roasting and steaming are physical treatments that proceed by cooking the food, respectively, by direct or indirect transfer of dry heat and by indirect transfer of moist heat to the food (Karanth *et al*., 2023; Choe *et al*., 2022). Fermentation, which is a biological treatment, is said to be one of the oldest methods of food preservation best shared by humanity (Augustin *et al*., 2024; Marco *et al*., 2021). It consists of the action of autochthonous fermentation microorganisms (spontaneous fermentation) or non-fermentation microorganisms (fermentation induced by a starter), in an appropriate environment. The resulting physicochemical changes result in the lowering of the pH to limits hostile to undesirable pathogenic and non-pathogenic microorganisms (Yang *et al*., 2025; Zhang et al., 2025). Some strains of fermentative microorganisms called "probiotics" are thought to influence the technological properties, which are precursors of beneficial effects for the nutrition, well-being and health of the host (Tonacci and Gorini, 2025; Hill *et al*., 2014 **)**. The economic importance of probiotics, whose global market has been estimated at more than USD 100 billion in 2024, is

believed to be the source of thousands of scientific publications and patents each year (IAP, 2025).

Millet (*Pennisetum glaucum* L. R. Br.) is a resource that contributes strongly to the food and financial resilience of the poorest populations (Ecofin Agency, 2023). It is a cereal with high nutritional value, gluten-free, which adapts to harsh edapho-climatic conditions and technological innovations (FAO, 2024). According to Songré-Ouattara *et al*. (2016) ; Békoye (2014), the levels that would depend on geographical, agro-pedological and varietal factors, would vary between 9.7 - 12.5% for proteins; 3.5 - 5.2% for fat; 60.9 - 67.0% for carbohydrates; 89.6 – 97.0% for dry matter and 2.2 – 5.4% for ash. Slug is grown by about 40% of farming households and is one of the main cereal crops in Burkina Faso (INSD, 2023). Average annual national production was estimated at 926,900 tons over the period 2015-2024 (USDA, 2025). Tigernuts(*Cyperus esculentus* L.)is a tuber with many nutritional and ethno-medical virtues. The production of the country's three main producing regions (Cascades, Hauts-Bassins and Sud-Ouest) was 2080.82 tons in 2017 (Soméet *al*., 2021). This production, which is comparable to domestic production, is partly exported. Annual exports of Tiger nuts increased from 451,475 tons in 2022 to 898,268 tons in 2024. According to Traoré *et al*., 2024; Semdé*et al*., 2019, the concentrations would vary from 3.28 to 9.70%; from 20.30 to 35.21% and from 33.70 to 69.21% respectively for proteins, fats and carbohydrates. These levels are influenced by genetic and agro-pedological factors.

In addition to these agronomic performances, Burkina Faso is characterized by agro-industrial underperformance, which limits the value of production, and thus leads to the country's dependence on imports of manufactured agricultural products, such as pasta and biscuits. From 2020 to 2023, the country disbursed about 10.458 million US dollars, or nearly 6 billion CFA to import biscuits and similar products (Trade_Map, https://www.trademap.org/Product_SelCountry_TS.aspx. Page consulted on 14-03-2025). Bougma *et al*. (2023) reported that the consumption of biscuits and cakes would represent 62.94% of the food matrix of children in Ouagadougou. This rate would place these foods in 3rd place, after porridges and common dishes (*Tô* and rice). According to Chavan *et al*. (2016), the term "biscuit" would mean baked twice (*bis coctus)* in Latin.Cookies are forms of eating cereals whose first ingredient is flour. Their presence in the human diet dates to the sedentarization and domestication of cereals in antiquity (Denis, 2011). Authors such as Chavan *et al*. (2016) ; Huber and Schoenlechner, (2016) indicate that the term "biscuit" includes several types of products with different names, flavors and formulations from one country or culture to another (Biscuit, Cookie, Crackers, Scone, etc.). The application of adequate biotechnology to the combination of millet and tiger nuts could contribute to the development of innovative, competitive food products with functional potential, with a view to satisfying nutritional challenges. The purpose of this study was to evaluate the effects of two technological treatment methods on the proximal composition and sensory acceptability of millet and tiger nuts-based cookies-type foods and enriched with probiotics.

Materials and methods

Material

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Plant material

The millet and tiger nuts were purchased on the local market in the town of Bobo-Dioulasso in Burkina Faso. The flours were obtained by adapting (roasting) the production processes for millet and tiger nuts flour described by Oyedele *et al*. (2022).

Methods

Pretreatments

The millet grains and the raw tiger nuts tubers were subjected to several cleaning operations. Thus, after winnow, which made it possible to eliminate the least heavy physical impurities (grains of sand, plant particles, etc.), the grains and tubers were washed and rid of the heaviest physical impurities such as pebbles (de-stoning), defective grains and tubers (sorting). The batches were then dried in a RoHS brand dehydrator, model FDS-018), at 37°C for 24 hours, to prevent any risk of alteration and soiling.

Preparation of the sourdough

The sourdough was prepared by transplanting strains of lactic acid bacteria from the Trunature and Spring Valley brands and a strain of pharmaceutical yeast (Ultra yeast), on tiger nuts "milk". Two capsules of lactic acid bacteria (Bifidobacterium and lactobacillus at 14 x 109 U) and a sachet of yeast powder (*Saccharomyces cerevisiae Boulardii* at 5 x 109 U) were inoculated with 100 mL of tiger nuts "milk" maintained at 37°C. The mixture was then incubated at room temperature for 24 hours, before use. The tiger nuts "milk" had been obtained according to the processes described by Jade *et al.* (2024); Oyedele *et al*. (2022).

Technological treatments

Production of roasted flour

The raw millet kernels and nutsedge tubers were placed in the oven preheated to 110°C of a Silver Crest fryer, model AF-15, equipped with an oven with timer, and with adjustable temperature from 0 to 300°C. The roasting lasted 15 minutes. The beans and tubers were then cooled (37°C) in ambient air, before being ground using a Silver Crest brand shredder-mixer, model SC-1589 witha variable speed between 0 and 45,000 rpm. The sieving was carried out with a sieve of 0.5 mm mesh.

Production of steamed lumps

Raw millet grains and raw tiger nuts tubers were ground to obtain raw flour. A composite flour (50:50) was successively rolled manually, graded by sieving to 1mm and steamed for 45 minutes using a Stainless-steel couscous maker.

Production of fermented cookies-type foods

The common food production operations included:

- **Hydration**: Boiling water gradually poured over the roasted flour and steamed lumps, kneading until the desired gel consistency was achieved. The quantities vary between 20 and 35 mL of water per 100g of dough.
- **cooling**: the scalded dough was placed in a refrigerator until they cooled to 37°C.
- **sowing**: it was carried out at a rate of 1 mL of sourdough for 100 g of dough.
- **moulding:** the seeded gels were moulded using a manual piston moulder with multi-shaped lids to obtain fresh cookies.

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- **fermentation/dehydration:** the fresh seeded cookies were placed for 15 hours at 37°C, in a RoHS brand dehydrator, model FDS-018, with a heating element adjustable between 0 and 100°C, and a laminar airflow propellant fan.

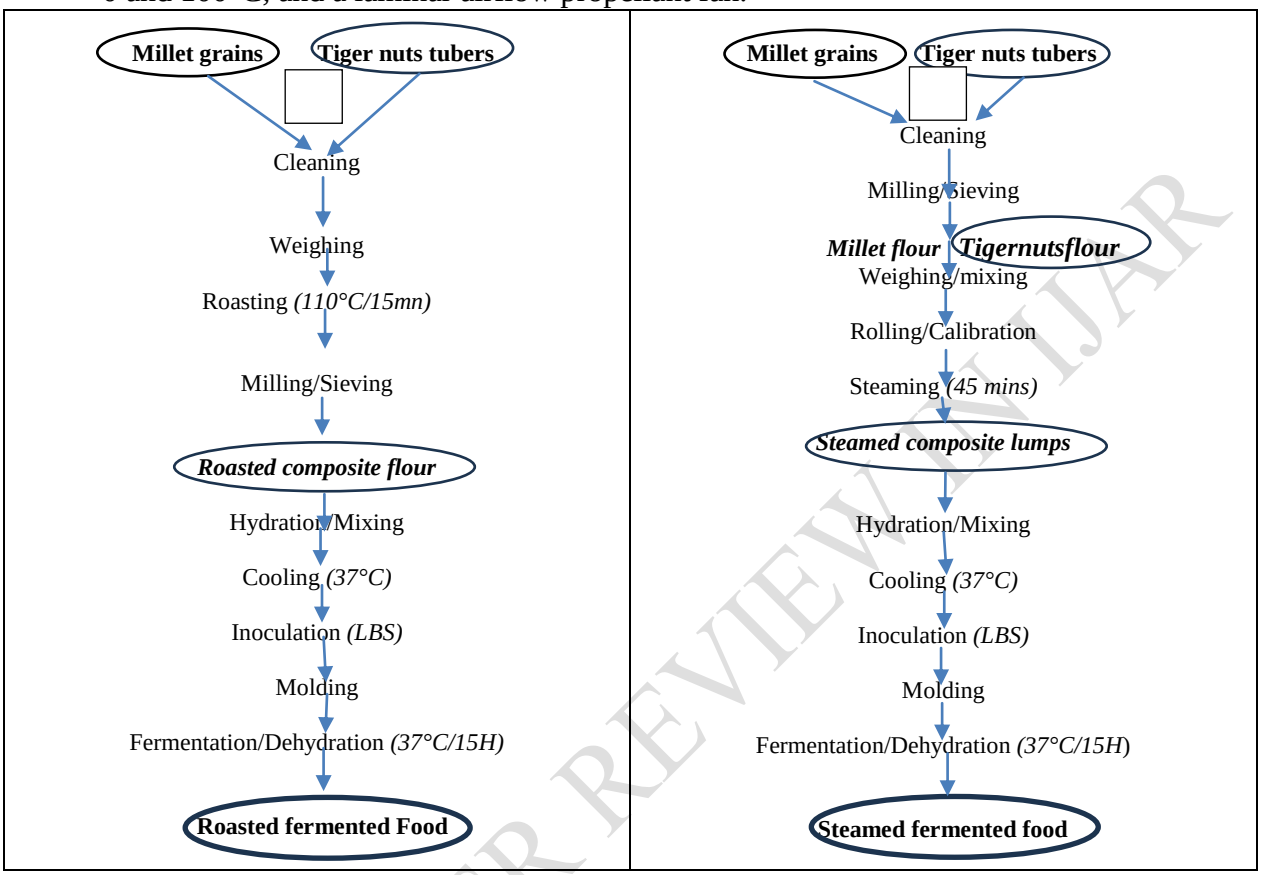

Figure 1: Fermented cookies foods production diagram
***a*=*Roasting-fermentation*, *b*=*Steaming-fermentation*,**
LBS* = *lactic acid bacteria + S. boulardii

Determination of total carbohydrate content

Total carbohydrates were measured according to the method of Dubois *et al*. (1956) adapted by Tajini *et al*. (2020), using phenol and sulphuric acid. The formation of a yellow-orange chromophore made it possible to measure the optical density at 485 nm.

Determination of total protein content

Total protein content was assessed according to the Kjeldahl reference method described in AOAC 979.09 (1999). This method is based on the mineralization of the organic nitrogen of the proteins into ammonium followed by its quantification by acidimetry.

Determination of lipid content

Lipids were quantified by the adapted Soxhlet method, described in AOAC (1990). Hot extraction was done in boiling hexane, which was subsequently removed by evaporation and the residue weighed.

Determination of water and ash content

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Water and ash levels were determined using the thermogravimetric method (AOAC, 1990). The determination of the water content consisted of the removal of the water from the sample by heating 105C for 24 hours. The determination of the ash content was based on the removal of organic matter by drying the sample in a furnace heated to 600°C for 180 minutes; then the mass of the ash was determined from the weighing of fresh and residual samples.

Evaluation of the effects of thermization methods on proximal compositions

The effects of roasting and steaming on the proximal compositions of flour, lumps and fermentation on the proximal composition of cookies-type foods were determined through the rates of variation of the proximal compositions of the different products according to the following formula:

$$\mathrm{RC} = \frac{\text{PC after traitemnt} - \text{PC before traitemnt}}{\text{PC before traitemnt}} X\ 100$$

With:

RC: Rate of change

PC: Proximal composition

Sensory analysis of cookies-type foods

The sensory analysis was carried out by adapting the ISO 11136 standard on hedonic tets described by Majou *et al. (2014). The number of respondents was defined according to Schwartz's formula*[1] (**Equation 1**). The respondents were randomly met in pre-identified public squares (markets, large sales stores, school and university exits) in the cities of Ouagadougou, Bobo-Dioulasso and Banfora. Respondents were able to sample both types of fermented foods (roasted flour and steamed lumps). Each sample underwent 3 tastings (preceded by water intakes), before filling in the questionnaire. The questionnaire, generated using the Kobotoolbox software, identified 5 specific organoleptic attributes (shape, color, smell, taste and texture), evaluated on a 5-point scale. The overall assessment, which expresses the respondents' overall level of satisfaction with the sensory profile of each type of cookies -type foods, was rated on a 10-point scale. The acceptability of "cookie" type foods was determined by three response methods: "*YES*", "*NO*", "*don't know*", to the question "would you agree to eat this cookie"? A suggestion section also made it possible to collect the proposals for improvement desired by the respondents.

$$\mathrm{n} = \mathrm{z}^2 \mathrm{x}\ \mathrm{p}\ (1 - \mathrm{p})/\mathrm{m}^2$$

Equation 1: Schwartz's formula

n= minimum sample size; z= value of the normal distribution corresponding to the confidence level; z= 1.96 for 95%; p= estimated proportion of the population that has the characteristic (representative), p=50% if unknown. ; m= tolerated margin of error, m=

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Statistical analysis

Three outlets were used for each measurement. Proximal compositions were expressed on average. The Excel Office 365 and R studio 3.14, Jamovi 2.6 software were used for data processing and analysis. The comparison of the sensory perception of fermented cookies- type foods was carried out using the radar histogram (Majou *et al., 2014; Tapsoba et al.*, 2022). Statistical significance was set at 5%.

Results

Proximal composition of flour, lumps and cookies-type foods

Table I presents the proximal compositions of raw and roasted composite flours, steamed lumps and fermented cookies-type foods. Roasted composite flour was richer in protein (21.59 ±0.00%) and fat (15.19±0.01%) than raw composite flour. In contrast, raw composite flour had better carbohydrate contents (60.49±0.84%), and steamed lumps were richer in water (14.27±1.30%) and ash (1.45±0.02%). The highest levels of protein (21.73 ±0.63%), ash (1.75±0.11%) and water (12.18±4.01%) were obtained with the cookies-type foods processed by roasting-fermentation, compared to the cookies- type foods prepared by steaming-fermentation which were richer in fat (15.07±0.02%) and carbohydrates (37.13±0.05%).

Table I: Proximal composition of flours, lumps and cookies-type foods (%DM)

Technology Matrices	Protein	Fat	Carbohydrates	Water content	Ashes
Cleaning and grinding					
Raw composite flour	17.66±0.00[a]	13.34±0.24 [a]	60.49±0.84 [a]	9.70±0.32 [a]	1.20±0.53 [a]
Roasting					
Composite flour	21.59±0.00 [b]	15.19±0.01 [b]	48.00±0.01 [b]	8.82±0.18 [b]	1.02±0.07 [b]
Steaming					

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Composite lumps	17.39±0.10 [c]	14.69±0.11 [c]	48.60±0.11 [c]	14.27±1.30 [c]	1.45±0.02 [c]
Fermentation					
Roasted flour food	21.70 ±0.63 [d]	14.75±1.69 [c]	36.74±1.42 [d]	12.18±4.01 [d]	1.75±0.11 [d]
Steamed lumpsfood	19.63±0.06 [e]	15.07±0.02 [d]	37.13±0.05 [e]	8.12±0.03 [b]	1.48±0.03 [e]

***DM** = DryMatter*

The values in the same column with different superscript letters are significantly different.

Effects of roasting-fermentation and steaming-fermentation on the proximal composition of cookies-type foods

Table II shows the rates of change in proximal compositions during the production of cookies foods. Negative values indicate a reducing effect of the proximal composition, while positive values indicate an improvement in concentrations. Roasting induced a reducing effect on the carbohydrate (-20.64%), water (-9.13%) and ash (-15.20%) compositions compared to raw composite flour. However, this treatment led to an improvement in the protein (+22.30%) and lipid (+13.88%) content of this flour. Steamed lumps also showed a reduction in protein and carbohydrate content compared to an improvement in other parameters, compared to raw composite flour. For food based on roasting-fermentation, an increase in proximal compositions of protein (+0.64%), water content (+38.13%) and ash content (+71.73%) was observed compared to roasted composite flour. Concerning steaming-fermentation process food, and according to the composition of the steamed lumps, improvements were also noted in the protein (12.85%), lipid (2.56%) and ash content (2.49%).

Table II: Rates of change in proximal compositions during cookies-type foods production

Technology Matrices	**Protein**	**Fat**	**Carbohydrates**	**Water content**	**Ashes**
Roasting					
Roasted flour/Raw flour	22.30%	13.88%	-20.64%	-9.13%	-15.20%
Steaming					
Steamed lumps/Raw flour	-1.50%	10.17%	-19.65%	47.07%	20.85%
Fermentation					
Roasted food/Roasted flour	0.64%	-2.89%	-23.46%	38.13%	71.73%
Steamed food/ Steamed lumps	12.85%	2.56%	-23.60%	-43.10%	2.49%

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Socio-demographic profiles of respondents

The sensory analysis of cookies- type foods was carried out on 380 respondents, of whom 52.63% were female and 47.37% male. The respondents were aged between 7 and 77 years (Figure 2a) and were mainly in the [7 to 27] age group (63%) followed by the [28-47] age group (24%). Their socio-professional profile was pupils and students (50.76%), and they worked in commerce or manual trades (21.32%). Employees in the public and private sectors (20.78%), the unemployed and other undeclared jobs (7.14%) were also represented (Figure 2b).

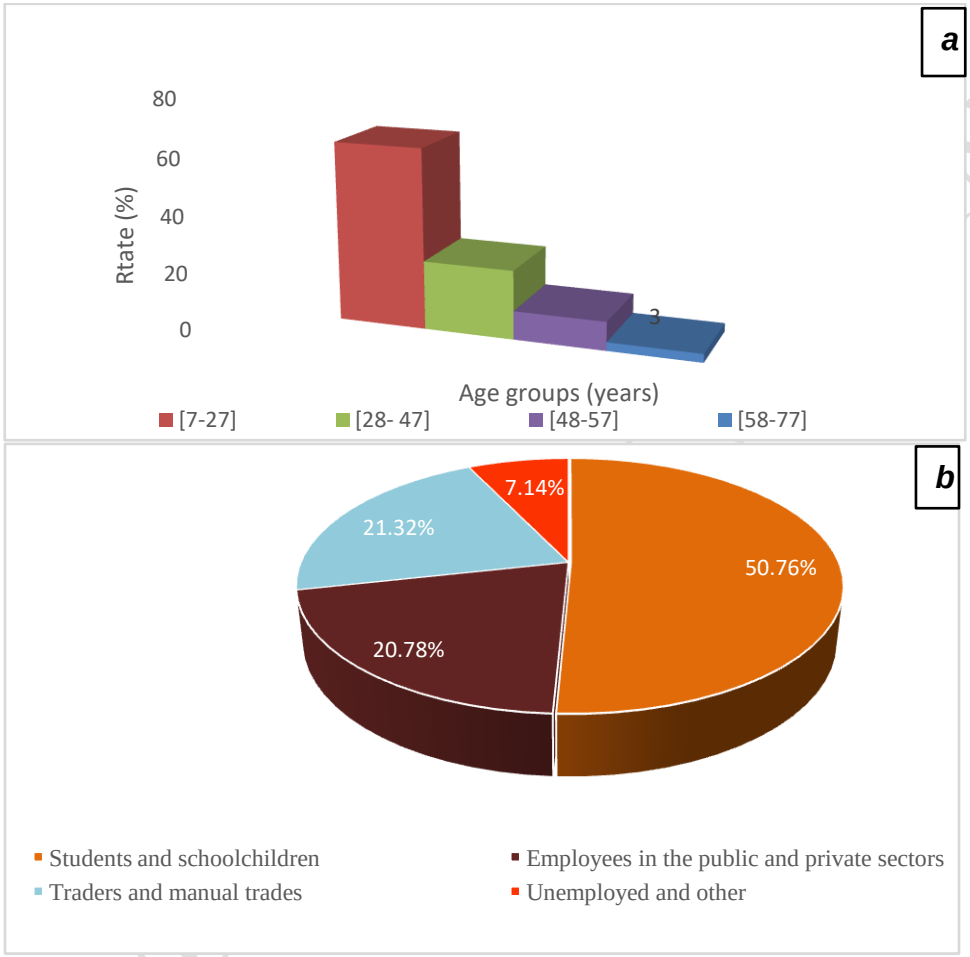

Figure 2: Socio-demographic profiles of respondents.
a= Distribution of respondents by age; b= Socio-professional profile of respondents

Sensory profile and overall appreciation of "cookie" type foods

Figure 3, which presents the sensory profile of cookies- type foods, shows that the overall assessment was in favor of cookies- type foods produced by roasting and fermentation ($p = 0.007$), mainly in relation to shape ($p = 0.289$), color ($p = 0.001$) and taste ($p = 0.001$).

Figure 3: Sensory profile and overall appreciation of cookie-type foods

Acceptability ofcookies- type foods by respondents

Table III presents the acceptability rates of cookies- type foods given by the respondents who answered this question. Foods obtained through roasting and fermentation recorded the best acceptance rate by respondents (81.32%).

Table III: Acceptability of cookies-type foods by respondents

	Roastedfermented food		**Steamedfermented food**	
	Acceptability (%)	**Effectifs**	**Acceptability (%)**	**Effectifs**
Yest	81.32	309	77.37	294
No	13.16	50	20. 00	76
Don't know	5.47	19	2.39	9

Discussion

The purpose of this study was to evaluate the effects of two technological treatment methods on the proximal composition and sensory acceptability of probiotic-enriched millet and tiger nuts-based cookies-type foods. The results of the physicochemical analyses show that the roasting resulted in a roasted composite flour that was richer in protein and fat than the raw composite flour, which had better carbohydrate and ash contents. These results also indicate that steaming the lumps resulted in lower protein and carbohydrate contents, compared to higher fat and ash levels compared to raw composite flour. Similar results were obtained by Gwekbe *et al*. (2024); Lien *et al*. (2024) ; Li *et al*. (2023). Increases in levels may result from inhibition of catalytic enzymes and concentration of the material, following the reduction of water content by heat. The

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weakening of cell membranes and intermolecular bonds by heat, which facilitates the extraction of molecules, would also lead to higher concentrations of certain components. (Link *et al*., 2024; Zhang *et al*., 2024; Li *et al*., 2023; Sefrienda *et al*., 2023). The reductions could be consequences of the thermal denaturation of certain molecular structures or the formation of stable macro-complexes (Scott and Awika, 2023; Zhuang *et al*., 2022; Toda *et al*., 2019). Heat treatments that generate volatile fat compounds are reported to be accompanied by reductions in lipid levels (Kong *et al*., 2024; Li *et al*., 2020; Zhang *et al*., 2020). Hydrolysis, oxidation and the Maillard reaction are also thought to reduce the content of certain nutrients (Hong *et al.*, 2022; Zhuang *et al.*, 2022; Guo *et al.*, 2020).

Regarding the effects of fermentation, a comparison of the proximal composition indicates that the cookies- type food obtained from roasting-fermentation showed an increase in protein and ash contents, compared to roasted composite flour. Improvements were also noted in the protein, lipid and ash content of the cookies-type food prepared by steaming and fermentation, compared to cooked lumps. Our results agree with the results reported by Fawole *et al*., 2025; Lawrence *et al*., 2023; Chupeerach *et al*., 2021. Direct interactions between fermentative microorganisms and certain molecules for synthesis (Wu *et al*., 2024; Kiely and Hickey, 2022; Zhang *et al.*, 2021; Zhao *et al*., 2020), and the indirect inhibitory action of microorganisms on degradation factors, could lead to improvements in the contents of certain components (Rashwan *et al*., 2025); Alemayehu *et al*., 2023; Li *et al.*, 2020). Both types of fermented foods had shown reductions in carbohydrates respectively compared to roasted flour and steamed lumps. Cases of reductions would occur when the balance between the requirements of microbial nutrient metabolism and the availability factors (initial levels, technological increases) is deficient in certain nutrients (Emkani *et al*., 2022; Chupeerach *et al*., 2021; Ge *et al*., 2019).

The comparison between the roasted fermented food and steamed fermented food indicates that the highest protein and ash content was obtained with the roasted-fermented food compared to the steamed-fermented food, which was richer in fat and carbohydrates. Thermodynamic modifications on the different components would be accompanied by physicochemical phenomena that would vary according to the nature of the substrate, the treatment scales (time/temperature couple) and the environment (Ji *et al*., 2023).

Millet and tiger nuts are foods with high nutritional value that can help fight undernourishment (FAO, 2024; Gwekbe *et al*., 2024; Pudake *et al*., 2024; Ban-Koffi *et al*., 2005 ;). The richness of the cookies-type food obtained by roasting-fermentation in proteins and ash could support its recommendation for vulnerable groups such as pregnant women (embryo development), young children (muscle and bone growth) and immunocompromised people (Järvinen *et al*., 2024; Ganapathy and Nieves, 2020; Matonti *et al*., 2020). In addition, the richness in proteins and lipids makes the two cookies-type foods alternatives for people suffering from protein-energy malnutrition (Bompart and Gueugneau, 2024). Their low carbohydrate content makes them compatible with hypoglycemic diets. Combining heat pretreatments with fermentation could help optimize feed characteristics according to target populations. Indeed, moderate thermization improves the nutritional value of foods by increasing the content and digestibility of certain nutrients (Ghosal *et al*., 2024; Lu *et al*., 2023) but does not necessarily guarantee sensory quality.

The sensory perception of the respondents showed an overall appreciation essentially in favor of the color and taste of the cookies- type food obtained by roasting and fermentation (Figure 3). A

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better acceptance rate was also recorded with this feed (Table 3). The major suggestions for improvement were related to the sweet taste. The tastes of the two foods are statistically different ($p<0.001$). This corroborates the results of the physicochemical analyses (**Table 1).** There was no correlation between the suggestions to "sweeten" and the age or sex of the respondents, despite most young people and women. Bobowski and Mennella (2017) had noticed that children had a higher preference for sweetness than adults. Mennella, Petty *et al*. (2020) reported a relationship between sucrose detection limit and age. Children showed lower sensitivity than adolescents, who themselves were less sensitive than adults. Environmental factors and dietary habits that may influence this sensitivity (Appleton, 2024; Mannella *et al*., 2005).

Conclusion

This study shows that roasting and steaming have a different impact on the flour components of raw millet and Tiger nuts. The effects of fermentation on the proximal composition of fermented foods such as "cookies-" were influenced by the nature of the substrate and the mode of thermization. The results of the sensory evaluation indicate that the effects of technological processing methods determined the sensory profile of fermented foods such as cookies-type foods. This study suggests that the production of protein-rich and sensorially acceptable foods, without the use of processing aids and additives, often suspected of harmfulness, remains a biotechnological challenge accessible. However, further investigations, such as resistance tests of inoculated probiotics to gastrointestinal stress, the impact of the consumption of "cookies-" type foods on well-being and health, the characterization of the probiotic strains counted, etc., remain necessary to support the probiotic qualification of the "cookie-" type foods proposed.

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