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Technological, physico-chemical and microbiological characterization of local plant-based infusions produced in Burkina Faso

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Nowadays, local plant-based infusions represent the second most consumed drink in the world after water because of their therapeutic virtues. Several types of infusions are produced from different local plants and consumed in Burkina Faso. However, there are few studies on the production technology and quality of these infusions. This study is aimed at assessing the production technology and the quality of lemongrass, kinkeliba and moringa leaves-based material used for infusions. For this purpose, 12 batches of samples from different manufacturers were collected for microbiological and physico-chemical analyses. Microbiological analyses revealed a total absence of *Salmonella* and *Shigella* in all infusions as well as a total flora, spore-forming flora, total and thermotolerant coliforms counts within normal ranges according to the European Pharmacopoeia standards for microorganisms and the Burkina Faso standards (NBF) for yeasts and molds. Physicochemical analyses indicated dry matter values of 92.42±0.71, 91.63±4.20 and 91.10±1.80% for kinkeliba, lemongrass and moringa dried leaves, respectively. Moisture values were 7.25±0.76, 8.37±4.20 and 8.90±1.80% for kinkeliba, lemongrass, and moringa dried leaves, respectively. Infusions obtained from the dried leaves gave average pH values of 6.46±0.12, 5.97±0.26 and 6.00±0.10 for kinkeliba, lemongrass, and moringa infusions, respectively. Acidity values obtained were 0.04±0.01, 0.05±0.01 and 0.00±0.00 for kinkeliba, lemongrass, and moringa infusions, respectively. The results indicate that 50% of the kinkeliba infusions and 75% of the lemongrass infusions complied with the NBF standards. Overall, results indicate that majority of infusions prepared from dried leaves of kinkeliba, lemongrass and moringa complied with standards, reflecting an acceptable level of good hygiene and manufacturing practices of local manufacturers.

Key words: Infusions, local plants, technology, quality, Burkina Faso.

INTRODUCTION

Plants have long been valued around the world for their medicinal properties and are the subject of many studies (Belfarhi et al., 2020). Herbal teas were the sole means of healing during ancient times. Like all plant foods, herbal teas begun to occupy an important place in new product development in recent years. This is due to the increased awareness of their health benefits (Belfarhi et al., 2020). Approximately, 70 to 80% of the world's population,

especially those in developing countries, use plant-based medicines for health care. Tea infusion is one of the most consumed beverages in the world after water (Akyuz and Yarat, 2010). Herbal teas are aqueous preparations of whole medicinal plant or part of its organs (Bournier, 1997). They are classified into two categories: simple herbal teas (intended for daily use) and complex herbal teas that is for therapeutic use (Belfarhi et al., 2020). There are several types of tea infusions in the form of black, white, green or natural plant-based teas (Akyuz and Yarat, 2010). They can be obtained by maceration, decoction or infusion (Ouédraogo et al., 2021). Infusion is the simplest form of preparation, commonly referred to as "tea". It is a substance obtained by solubilizing the active principles or aromas of a plant infused in boiling water (Bournier, 1997). Numerous studies have shown that tea infusion has many benefits for human health. It can protect against cancers and cardiovascular diseases (Chen et al., 2009). The use of raw materials of natural origin from medicinal plants is a very old practice in Burkina Faso, as in many African countries (Nicolas, 2009). Phytochemicals of therapeutic interest can be derived from many parts of the plant such as bark, leaves, flowers, roots, fruits, and seeds with variable contents. These biologically active compounds can be isolated from the plant by traditional processes such as herbal teas (Ouédraogo et al., 2021). In view of its socio-economic benefits, the plants have gone from being a marginal, even unknown, plant to a new food and economic resource (Djibo et al., 2017). They are cultivated in Burkina by both urban and rural populations mainly for the leaves used in local food but also sold nationally and internationally (Dao et al., 2016). Recent studies have also shown that local plant-based infusions inhibit the growth of microorganisms such as *Pseudomonas* and *Staphylococcus aureus* (Anwar et al., 2007). In Burkina Faso, a variety of local plant-based infusions are available, including mint, moringa, lemongrass and kinkeliba. However, there are few studies on the technology and quality of these herbal teas. This study evaluated the production technology of three local plant-based ingredients namely moringa, kinkeliba and lemongrass leaves used for infusions, as well as the sanitary quality of resulting infusions. For this purpose, physico-chemical and microbiological parameters of dried plant leaves and resulting infusions were analysed.

MATERIALS AND METHODS

Sampling and production monitoring

The production technology of local plant-based ingredients for infusions was followed step by step in order to draw up the production diagram. In an aseptic and random way, 4 samples of dried plant leaves packaged in teabags of 5 g each were collected twice from two production units in Ouagadougou. These samples were put in a sterile bag and sent to the Laboratory of Applied Biochemistry and Immunology (LaBIA) of University Joseph KI-ZERBO in Ouagadougou where they were kept at room temperature for physicochemical and microbiological analyses. Table 1 shows the samples' distribution.

Production process of dried plant leaves for infusions

The production monitoring allowed us to develop the production diagram of dried plant leaves for infusions. Figure 1 shows the production diagram of the dried leaves for moringa infusions. The different stages of production are sorting, washing, draining, drying, grinding, and packaging. The first stage of sorting allows to detach leaves from their petiole, to sort out yellow leaves, blackened leaves as well as any foreign or undesirable body. Washing allows to remove the dust and other undesirable deposits. The leaves are then drained before drying in order to remove part of the washing water. The drying step allows reducing the water activity of leaves, which value influences the microbial presence. Indeed, several studies have shown that a low water activity following drying, salting or sugaring operations limited the multiplication of microorganisms and consequently ensured a sanitary guarantee (Güçer and Miran, 2023). Then, the dry leaves are ground in a stainless-steel mill with a sieve to eliminate undesirable elements and to obtain the desired size according to the raw material. After packaging in filter papers, the products obtained are packaged a second time in sterile and dry secondary packaging that preserves the products' quality. Finally, each package is properly sealed to avoid leakage and absorption of moisture.

Figure 2 shows the production steps for kinkeliba and lemongrass dried leaves for infusions, which are similar to those described for moringa infusions. The same steps have been recorded but with a slight difference, especially after draining, and during drying. The steps are therefore sorting, washing, draining, drying, grinding, and packaging.

Physicochemical analyses of infusions

pH

The pH of the samples (dried plant leaves) was measured according to the AOAC method (AOAC, 1990). Thus 10 g of each sample was placed in 25 mL of boiling water for 5 min. After cooling the infusion, the pH was measured using a HANNA instruments type pH meter, previously calibrated with buffer solutions at pH 4 and pH 7, by dipping the pH meter's electrode into homogenized mixtures.

Free acidity

The free acidity of infusion samples was determined by volumetric titration according to the AFNOR method (NF V05-101, 1974). Thus, 10 g of each sample were dissolved in 25 mL of boiling distilled water contained in beakers. After cooling the infusion, each preparation was well homogenized with a few drops of phenolphthalein titrated with a 0.1 N NaOH solution until a pink coloration was obtained. The results were determined according to the following formula:

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Table 1. Distribution of samples by infusion.

Sample	Code	Quantity (tea bags)
Kinkeliba	*KI1, KI2, KI3, KI4*	08
Lemongrass	*LI1, LI2, LI3, LI4*	08
Moringa	*MI1, MI2, MI3, MI4*	08
Total		24

KI: *Kinkeliba* dried leaves for infusion; LI*: Lemongrass* dried leaves for infusion; MI: *Moringa* dried leaves for infusion.

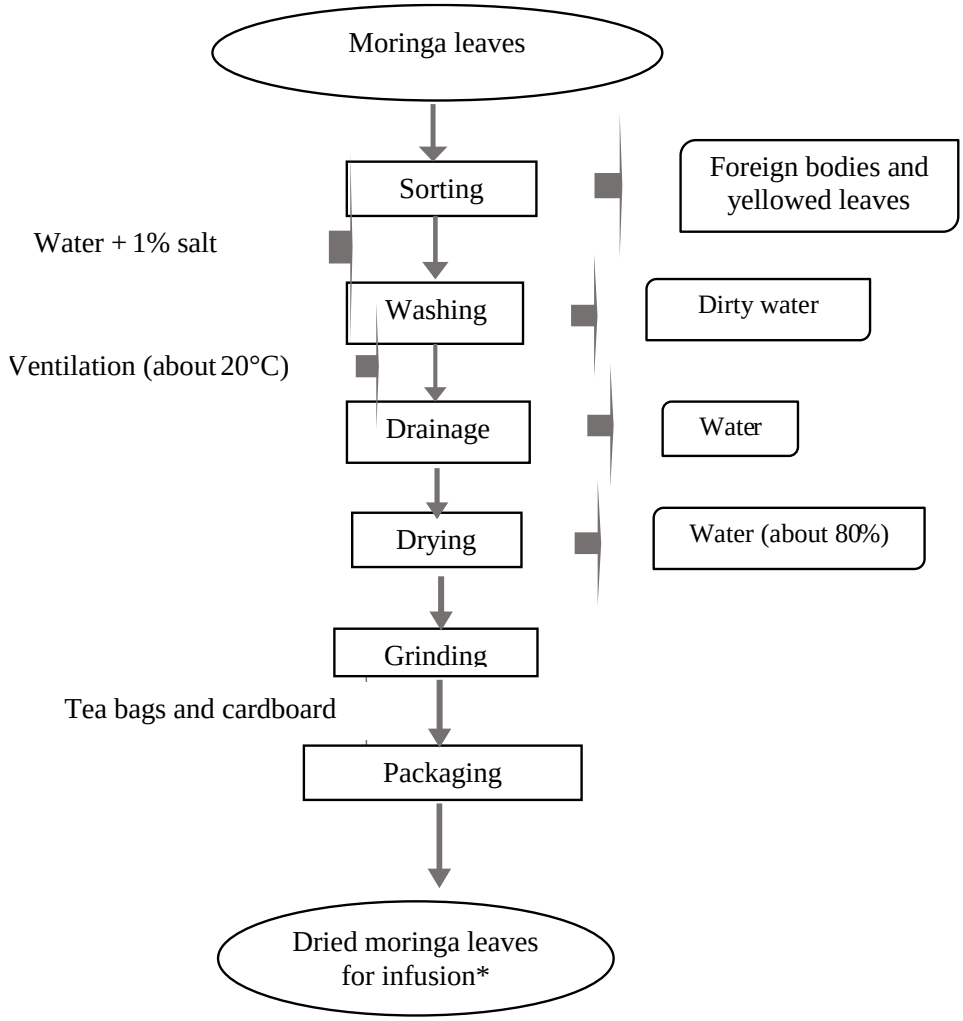

Figure 1. Production flow chart for *Moringa oleifera* dried leaves for infusions. *Dried moringa leaves packaged in teabags.

$$\text{Free acidity} = \frac{(V \times N \times 0.070)}{Vp} \times 100$$

N: normality of (NaOH); V: volume (in mL) poured into the sample at the equivalence; 0.07: conservation factor in citric acid; Vp: volume of the sample in mL.

Determination of the moisture and dry matter

The moisture of the samples was determined according to the AOAC method (1990). Five grams of the dried plant leaves samples were weighed into aluminum weighing boats that had been washed dried and tared. The sample was then placed in a ventilated oven at 105°C until complete elimination of water. The moisture was expressed according to the following formula:

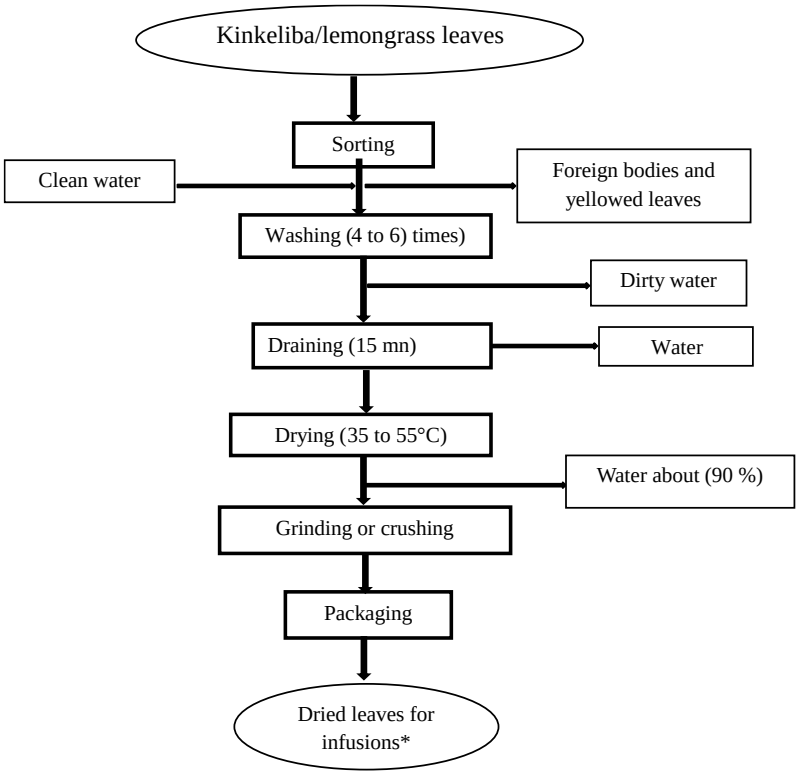

Figure 2. Production diagram of kinkeliba/lemongrass dried leaves for infusions.
*Dried kinkeliba/lemongrass leaves packaged in teabags.

$$TE\ (\%) = \frac{(PF-P0)\times 100}{PE}$$

TE: moisture; PE: test sample; P0: empty weighing boat weight; PF: final weight (weighing boat + dry sample).

Dry matter (DM) is the remaining part of a fresh biological sample after drying at 105°C. The DM content was calculated by the following formula:

DM (%) = 100 - TE (%)

DM: dry matter and TE: moisture.

Qualitative identification of tannins

The presence of tannin in infusion was determined using qualitative determination. One milliliter of plant-based infusion was added to 1 mL of $FeCl_3$ (1%) and observed for the development of a greenish or blue-black coloration as tannin presence indicator (Millogo et al., 2012).

Microbiological analysis of plant-based infusions

Preparation of physiological solution, stock solution and culture media

The stock solution of each sample was prepared by infusing 10 g of the sample in 90 mL of sterile peptone water. After homogenization, the 10^{-1} dilution was obtained. Cascade dilutions were performed up to 10^{-6}.

Depending on the examined microbe, different culture media were used. The different media were prepared according to the manufacturer's instructions. An appropriate mass was weighed and dissolved in a bottle containing an appropriate volume of distilled water. After homogenization, the culture media were autoclaved at 121°C for 15 min except for *Salmonella-Shigella* (SS) medium which was heated in a water device at 100°C for 30 min. After cooling to around 45°C, each medium was poured into sterile Petri dishes at a rate of approximately 15 to 20 mL per Petri dish.

Enumeration of the total aerobic mesophilic flora

The total aerobic mesophilic flora was enumerated according to NF ISO 4833-1(2013). Inoculation was performed on PCA medium at a rate of 0.1 mL per plate for dilutions of 10^{-2} to 10^{-3} and the plates were incubated in an oven at 37°C for 24 to 48 h. After the incubation period, plates containing less than 300 colonies were enumerated.

Enumeration of total and thermotolerant coliform

Enumeration of total and thermotolerant coliforms was performed according to NF ISO 4832 (2006). Plating was performed on EMB medium at a rate of 0.1 mL per plate for dilutions 10^{-1} to 10^{-2} and the plates were incubated in an oven at 37 and 44°C for 24 to 48 h. After the incubation period, the colonies were counted.

Enumeration of yeasts and molds

Yeasts and molds were counted according to the French standard ISO 08059 (2002) on Sabouraud medium. Plates were incubated at

25°C for 72 to 96 h. Dilutions from 10^{-1} to 10^{-2} were inoculated at a rate of 0.1 mL per plate. After the incubation period, colonies were counted.

Enumeration of spore-forming flora

Sporulating flora were counted according to NF/ISO 15213 (2002) on PCA medium. After heating at 80°C for 10 min in a water bath, dilutions from 10^{-1} to 10^{-3} were plated at a rate of 0.1 mL per plate and the plates were incubated at 37°C for 24 to 48 h. After the incubation period, colonies were counted.

Enumeration of Salmonella

Salmonella testing of infusions was performed in four successive steps as described by NF/ISO 6579-1 (2017). The presence or absence was detected in 25 g of product. The suspect colonies appeared black for *Salmonella* or *Shigella* on the SS medium.

The number of microorganisms contained in 1 g of the infusion was determined according to AFNOR standards. The calculation takes into account the plates of two successive dilutions. For plates containing between 15 and 300 colonies, the microbial load was calculated with the following standard enumeration formula:

$$N = \frac{\Sigma c}{V(n1 + 0.1n2)}$$

where N: number of microorganisms per gram of infusion; ∑C: sum of colonies counted on all retained plates of two successive dilutions; V: volume of the inoculum (mL); n1: number of plates from the first dilution; n2: number of plates from the second dilution; d: rate of the low dilution.

When all plates contained less than 15 colonies, the following formula was used:

$$N = \frac{\Sigma C}{V \times d}$$

When no colonies were observed in all plates, the following formula was used:

$$N = \frac{1}{d}$$

Statistical analysis

Statistical analysis of data was performed using Excel 2016 and XLSTAT-Premium.v2016.02.27444 software. The statistical analyses involved analysis of variance (ANOVA) which was used to compare the means by the Fischer multiple comparison test at 5% probability level. Means for each of the physicochemical analyses were obtained from three replicates.

RESULTS

Physico-chemical characteristics of local plant-based infusions

pH

The pH of kinkeliba sample before boiling water varied from 6.37±0.00 to 6.55±0.02 with an average of 6.43±0.01. For those infused with boiling water (kinkeliba infusion), the pH ranged from 6.4±0.01 to 6.57±0.07 with an average of 6.48±0.12.

For lemongrass infusions, the pH ranged from 5.72±0.01 to 6.16±0.06 with an average of 5.89±0.20 for the samples before boiling water infusion and from 5.72±0.01 to 6.32±0.03 with an average of 5.97±0.26 for those infused with boiling water.

The pH of moringa infusions ranged from 6 ± 0.01 to 6.13 ± 0.01 for the samples analyzed before infusion and from 5.97 ± 0.01 to 6.12 ± 0.01 for those analyzed after infusion with boiling water.

Acidity

Acidity of kinkeliba samples ranged from 0.04 ± 0.00 to 0.05 ± 0.00 before and after boiling water infusion. For lemongrass samples, it varied between 0.03 ± 0.00 and 0.04 ± 0.00 before infusion and 0.04 ± 0.00 and 0.05 ± 0.00 after infusion with boiling water.

Acidity values of *Moringa* infusions ranged from 0.02±0.00 to 0.05±0.00% for the analyzed samples before and after infusion with boiling water. The physicochemical characteristics of plant infusion samples are recorded in Table 2.

Qualitative analysis of tannins reveals that all samples of moringa infusion contain tannins with greenish coloration in the presence of $FeCl_3$ (Figure 3).

Microbiological characteristics of plant-based infusions

The results of microbiological analysis of kinkeliba, lemongrass and moringa infusions before infusion with boiling water are recorded in Table 3. They showed a difference between the samples analyzed before infusion.

The TAMF load ranged from 10^5 to $1.9.10^6$ CFU/g for kinkeliba samples before boiling water infusion.

Table 4 presents the results of microbiological analyses of kinkeliba, lemongrass, and moringa infusions after infusion with boiling water.

DISCUSSION

Physico-chemical analyses of kinkeliba samples infused in boiling water indicated a pH range of 6.4±0.01 to 6.57±0.07. The average pH was 6.42±0.12. This value is lower than the pH of iced teas (4.62) reported by Essebbahi et al. (2020). This average is higher than the pH of black tea (6.18) and lower than that of home-brewed teas (6.81) reported by Essebbahi et al. (2020). For infused lemongrass, the pH values ranged from 5.72±0.01 to 6.16±0.06 with an average of 5.97±0.26. These values are lower than those obtained with home-brewed teas

Table 2. Physicochemical characteristics of local plant-based infusions.

Infusion	pH	Acidity (%)	Dry matter (%)	Moisture (%)
KI	6.46±0.12	0.04±0.01	92.42±0.71	7.25±0.76
LI	5.97±0.26	0.05±0.01	91.63±4.20	8.37±4.20
MI	6.00±0.10	0.00±0.00	91.10±1.80	8.90±1.80
NBF standard 01-227 (2020)	-	-	-	≤7

KI: Kinkeliba sample; LI: lemongrass sample; MI: moringa sample

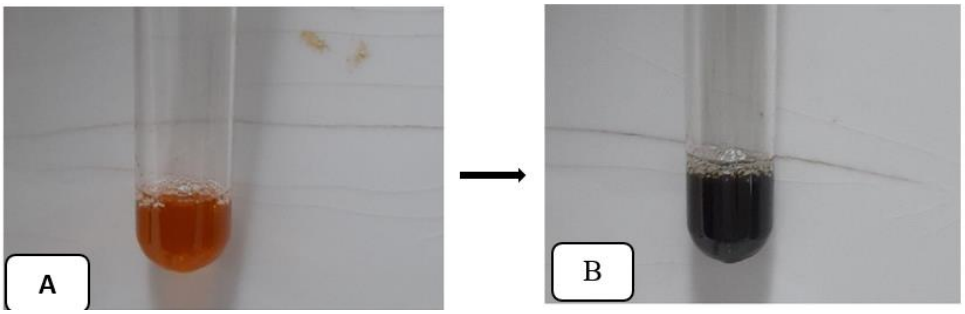

Figure 3. Identification of tannins. A: Infusion before addition of $FeCl_3$; B: Infusion after addition of $FeCl_3$.

Table 3. Microbiological characteristics of samples before infusion.

Sample	TAMF (UFC/g)	YM (UFC/g)	CT (UFC/g)	CTT (UFC/g)	SS	Appreciation
KI	7.40×10^5	3.55×10^2	2.08×10^3	2.80×10^2	Abs	Satisfactory
LI	5.05×10^4	1.51×10^3	3.84×10^3	2.90×10^3	Abs	Satisfactory
MI	5.70×10^5	1.40×10^4	1.00×10^4	6.40×10^3	Abs	Not Satisfactory
European Pharmacopoeia Standard (2007)	10^7	$<10^4$	10^4	10^4	Abs/25 g	Satisfactory

TAMF: Total Aerobic Mesophilic Flora: Total; YM: yeasts and molds; TC: total coliforms; THC: thermotolerant coliforms; SF: sporulating flora; SS: *Salmonella* and *Shigella*; Abs: absence; NBF: Burkina Faso standard; PE: European Pharmacopoeia. KI: kinkeliba sample; CI: lemongrass sample; MI: moringa sample.

Table 4. Microbiological characteristics of samples after infusion with boiling water.

Sample	TAMF (UFC/g)	LM (UFC/g)	TC (UFC/g)	THC (UFC/g)	SF (UFC/g)	SS	Appreciation
KI	4.90E+04	1.00E+01	1.00E+01	3.25E+01	7.75E+01	Abs	Satisfactory
LI	1.38E+03	3.25E+01	1.00E+01	1.25E+02	7.75E+01	Abs	Satisfactory
MI	5.87E+03	1.00E+02	1.00E+02	1.00E+01	1.00E+01	Abs	Satisfactory
European Pharmacopoeia Standard (2007)	10^7	$<10^4$	10^4	10^4	$<10^2$	Abs/25 g	Satisfactory

kI: Kinkeliba sample; CI: lemongrass sample; MI: moringa sample; TAMF: Total Aerobic Mesophilic Flora; LM: Yeasts and Molds; TC: Total Coliforms; THC: Thermotolerant Coliforms; SF: Spore-forming Flora; SS: *Salmonella* and *Shigella*; Abs: Absence.

(6.81) and green teas (6.84) reported by Essebbahi et al. (2020). Regarding moringa infusions, the pH ranged from 5.97 ± 0.01 to 6.12 ± 0.01 with average 6.00±0.00. These values are lower than those found by Ballogou et al. (2018) which was 6.71. This could be explained by the physicochemical characteristics of the soil. All moringa infusion samples can be considered as having a low acidic pH.

Average pH values also revealed a slightly acidic character for kinkeliba infusions and an acidic character for

lemongrass infusions with the general average of 5.93 ± 0.05. Acidity of the kinkeliba samples varied between 0.04 ± 0.00 and 0.05 ± 0.00 before and after infusion with boiling water.

The acidity values of infused moringa ranged from 0.02±0.00 to 0.05±0.00% for samples analyzed. These values are lower than those reported by Houndji et al. (2013) who observed acidity values of 0.7% moringa leaf powder. This could be explained by the nature of the samples, the cultivation conditions, the physicochemical characteristics of the soils and the non-control of the product temperature, the storage conditions of the raw material, the production technology, etc. These values also correlate with the determined pH values which shows that the product is weakly acidic. In addition, a low moisture of the samples could allow their conservation over a longer period of time.

The moisture values of infusion samples were 7.25±0.76, 8.37±4.20 and 8.90±1.80 for kinkeliba, lemongrass and moringa infusions, respectively. The moisture values are higher than NBF standard 01-227 (2020). These results could be explained by insufficient control of drying parameters or to moisture exchange between the product and the storage environment. Furthermore, the moisture could be the evidence that at room temperature still does not achieve the maximum desired level (Bankole, 2018).

The dry matter values are lower than those reported by Houndji et al. (2013) in moringa powder in Benin which was 95%.

All samples had a moisture lower than 10 and 50% of the kinkeliba samples complied with that set by standard NBF 01-227 (2020) (≤7%). Majority (75%) of lemongrass infusion showed satisfactory values as they were below the moisture threshold set by the NBF 01-227 (2020) standard, that is, less than or equal to 7%. Such samples can be kept for a long time. The non-conformity noted with regard to moisture could be explained by a rewetting of the dry plants during storage and warehousing or by the drying method at room temperature. Indeed, according to Bankole (2018) this technique (drying at room temperature) generally does not achieve the maximum recommended moisture rate of 10%. Yet, poor drying could affect the microbiological quality of samples because of the rather high amount of free water, favorable to the development of microorganisms. Therefore, it is important to use a suitable drying technique.

The qualitative identification of tannins also gave valuable insight about drying effect on their conservation. That is reflected by the greenish coloration (Figure 3B) indicating that drying allows a better conservation of tannins. This is beneficial for health given the numerous properties of tannins among which its therapeutic value.

Compared to the kinkeliba and lemongrass infusions, the use of $FeCl_3$ resulted in a blackish coloration that reveals the presence of tannins in all infusions. These results confirm the presence of tannins in these infusions, thus a therapeutic asset for health. Tannin content is a reasonable and important parameter for evaluating tea quality. Tannins have a protective role because they are able to bind to toxic substances and neutralize them in the gastrointestinal tract with subsequent excretion (tannins-toxic agent) via the stools. They are responsible for the unpleasant, astringent taste and also for the black-brown coloring of vegetable extracts. In addition, they have antioxidant, antibacterial and sometimes soothing properties (Koffi et al., 2015). They are used against hemorrhages and infections (diarrhea, wounds), and are deemed to cause tightening of tissues, capillaries, and orifices (Iserin et al., 2001).

Microbiological characteristics of plant-based infusions indicated a TAMF load ranging from 10^4 to 7.10^4 CFU/g in the lemongrass samples before infusion. The values obtained are below the recommended criteria by the standard for the microbiological quality of herbal remedy-like products (<10^8 CFU/g) reported by Bizot et al. (2007). Similarly, they are below the limits for the microbiological quality of medicinal herbs intended for the preparation of infusions or decoctions with boiling water (<10^7), established by the European stand pharmacopoeia (5.1.4 categories 4A). They are also within the range of contamination of medicinal plants (5×10^5 - 10^7 g^{-1} with a maximum of 10^8 g^{-1}) reported by Beckmann et al. (2003). These results indicate that the samples are satisfactory given their compliance with the limits set by the European Pharmacopoeia (5.1.4 categories 4A). This may reflect the respect of good hygiene practices (GHP) during the transformation processes.

In boiling water infused samples, after incubation, we found that the TAMF load was significantly reduced for all kinkeliba and lemongrass samples. For the kinkeliba infusions (KI), the load increased from $1.9.10^6$ to $9.5.10^4$ CFU/g at the sample with the highest value and from $1.6.10^5$ to $3.9.10^4$ CFU/g for the lowest. The TAMF load of the boiling water-infused lemongrass samples also decreased as it went from 10^4 to 10^3 CFU/g.

Thus, the TAMF loads of both KIs and LIs were reduced at least one tenth after boiling water infusion. This could be due to the temperature of water given that at this temperature, mesophilic microorganisms and vegetative forms are eliminated. Boiling water (100°C) is therefore an effective means of destroying or reducing microorganisms.

Compared to moringa infusions, the TAMF showed a microbial load ranging from $2.8.10^5$ to $1.07.10^6$ CFU/g before infusion and from 10^2 to $1.4.10^4$ CFU/g after infusion with boiling water. The lowest value was obtained with samples MI2 and MI3 and the highest value with sample MI1 (after boiling water infusion). These values could be considered satisfactory (before infusion and after boiling water infusion) because they remain under the threshold set by the European Pharmacopoeia (10^7 CFU/g). The observed variation could reflect recontamination during the transformation process.

Yeasts and molds were observed only in the kinkeliba

samples before infusion with non-boiling water with a predominance of molds. Samples KI2 and KI4 had the highest value ($1.3.10^3$ CFU/g) and the lowest value (10^2 CFU/g), respectively. In the other samples, yeasts and molds were below 10 CFU/g. In the lemongrass samples before infusion, only LI1 and LI4 had 10^3 and 5.10^3 CFU/g, respectively. These values are below the acceptance limits (10^5 CFU/g) set by the European Pharmacopoeia and reported by Bizot et al. (2007). They are also lower than those reported in Mali by Coulibaly (2008) for medicinal plants that were pre-treated with boiling water (maximum 10^4 CFU/g). These samples comply with the standards set by the European Pharmacopoeia (5.1.4 categories 4A). In the Kinkeliba and lemongrass samples infused with boiling water, loads up to 10^2 CFU/g of yeasts and molds were noted only on KI2 and LI4. The others had values below 10 CFU/g. These samples were considered satisfactory given that they comply with the values set by standard NBF 01-227 (2020), which are 10^3 and 10^4 CFU/g for yeasts and molds, respectively.

Regarding yeasts and molds in moringa infusions, they presented a microbial load between 10^3 and 5.10^4 CFU/g (before infusion) and < 10^2 CFU/g (after infusion with boiling water). These values are in conformity to the European Pharmacopoeia before infusion (10^5 CFU/g) and after infusion with boiling water (10^3 CFU/g), hence satisfactory. They were similar to those reported by Agassounon et al. (2012) in Togo. The low acidity of the samples could explain the presence of molds and yeasts in some samples (Anonymous, 2019). Indeed, drying at room temperature cannot guarantee mold-free leaves (Bankole, 2018).

Total coliforms ranged from 10 to 5.10^3 CFU/g and 10 to 10^3 CFU/g for KI and LI, respectively. These values are lower than those reported by Bizot et al. (2007) (10^4 CFU/g) regarding the microbiological quality of plant remedy-like products. In the boiling water-infused KI and LI samples, coliforms were below 10 CFU/g. This could be explained by the effectiveness of microbes killing or inactivation by boiling water.

Thermotolerant coliforms ranged from 10^2 to $5.8.10^3$ CFU/g for all samples. These values are similar and within the range of those reported by Bizot et al. (2007) between 10^2 and 2.10^4 g^{-1}. This could reflect compliance with good hygiene and manufacturing practices (GHP/GMP) during the production and drying processes. In the boiling water infused samples, thermotolerant coliforms ranged from 10 to 2.10^2 CFU/g for all samples. The highest value was obtained at the LI4 level (2.10^2 CFU/g). These values are below the microbiological limits of coliforms (10^3 CFU/g) reported by Abdolghani et al. (2020) for medicinal herbs.

For moringa infusions, total and thermotolerant coliforms were 5.10^3 to $2.4.10^4$ CFU/g and 10^2 to $2.4.10^4$ CFU/g before infusion, and <10^2 and <10 CFU/g after infusion, respectively. All these values (before infusion and after infusion with boiling water) are satisfactory as they are in conformity with the European Pharmacopoeia (10^4 CFU/g). These values are similar to those reported in Cote d'Ivoire by Koffi et al. (2015). They could be explained by a good application of hygiene measures during the production process of moringa infusions.

The sporulating flora load ranged from 10 to 10^2 CFU/g at the boiling water-infused KI and LI samples. These values obtained are lower than those reported by Abdolghani et al. (2020) (10^3 CFU/g) in the enumeration of sporulating flora (*Bacillus cereus*) in herbs. Spores of *B. cereus* and *Bacillus thuringiensis* are highly resistant against environmental stress such as low water activity, excessive pH values or heat (Thanh et al., 2018). Spore-forming germs *B. cereus* survived almost completely to boiling water treatment. These germs are mostly famous for causing food-borne infections due to the ingestion of foods contaminated by bacteria (Tirloni et al., 2022**)**. Another spore-forming enterobacterium, *Clostridium perfringens*, was also identified in the herbal teas (Bizot et al., 2007).

The values showed no difference between the different *Moringa oleifera* infusion samples. The spore-forming flora load was <10 CFU/g (after infusion with boiling water). These values are satisfactory with respect to the European Pharmacopoeia (10^2 CFU/g). This shows that the product does not contain bacteria producing spores. Storing herbal teas and infusions prepared for more than 24 h could pose a risk of food poisoning.

The results showed a total absence of *Salmonella* and *Shigella* in 25 g of infusion of all the samples analyzed. They are therefore, considered satisfactory according to the European Pharmacopoeia standard (Normes/lignes directrices de la Pharmacopée européenne, 2007) and the Burkinabe standard (absence in 25 g). Such result reflects the absence of faecal contamination as well as a good application of hygiene measures during production.

Conclusion

Improvement of the quality of products is one of the major concerns nowadays considering that improper food can cause sanitary as well as economic problems to the consumer. Therefore, we carried out the present study which allowed elaborating the production diagram of moringa, kinkeliba and lemongrass infusions. Furthermore, the microbiological and physicochemical qualities of the aforementioned plant-based infusions were assessed in order to improve the quality of the products.
The microbial load revealed a difference between samples analyzed before infusion and after infusion with boiling water for 3 min. Indeed, the microbial load decreased in infusion with boiling water for all the microorganisms searched. The microbial load values gave a satisfaction criterion for the researched microorganisms such as total aerobic mesophilic flora, thermotolerant total coliforms, spore-forming flora, *Salmonella* and *Shigella*. On the other hand, physico-chemical parameters' analyses indicated

moisture presence in a few samples. The results are generally consistent with previous research on plant-based teas. On the basis of the evaluated parameters and the analyzed samples, they demonstrate that local plant-based infusions produced do not constitute a sanitary risk for the consumer. In this respect, the study provides evidence of acceptable levels of good hygiene and manufacturing practices of local manufacturers. The study also suggests the microbiological effectiveness of boiling water on local plant-based infusions.

With respect to the few cases of non-compliance observed among the samples, it suggests a need to improve processes related to local plant-based teas production, mainly drying in order to avoid moisture. In the same vein, adoption of a quality and follow-up approaches by smallholder manufacturers is recommended.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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