

(RESEARCH ARTICLE)



ASSESSMENT OF THE TOXICOLOGICAL RISK ASSOCIATED WITH THE CONSUMPTION OF A TRADITIONAL BEER IN CÔTE D'IVOIRE: THE TCHAPALO

Aholia Jean-Baptiste Adepo ^{1,*}, Golou N'da Fidel N'guessan ², Jean Di-Maïssou ², Pierre Manda ², Kouakou Brou ¹ and Sébastien Djédjé Dano ²

¹ Laboratory of Nutrition and Food Safety, Faculty of Food Science and Technology, University of Nangui Abrogoua, 02 BP 801 Abidjan 02, Côte d'Ivoire.

² Laboratory of Toxicology and Agro-Industrial Hygiene, Faculty of Pharmaceutical and Biological Sciences, University of Félix Houphouët Boigny, B PV 34 Abidjan, Côte d'Ivoire.

* Corresponding Author

ORCID Details

Aholia Jean Baptiste Adepo: <https://orcid.org/0000-0003-1258-0703>

Pierre Manda: <https://orcid.org/0000-0003-3506-9246>

GSC Biological and Pharmaceutical Sciences, 2026, 37(01), 058–070

Publication history: Received on 29 August 2026; revised on 04 October 2026; accepted on 06 October 2026

Article DOI: <https://doi.org/10.30574/gscbps.2026.37.1.0344>

Copyright © 2026 Author(s) retain the copyright of this article. This article is published under the terms of the Creative Commons Attribution License 4.0

ABSTRACT

Background: Tchapalo is a traditional beer made by fermenting sorghum; it is widely consumed in Côte d'Ivoire and may be contaminated with various chemical substances. The objective of this study was to assess the toxicological risk associated with its regular consumption.

Methods: Forty samples of tchapalo were collected in four municipalities in the Abidjan district to test for chemical contaminants. A questionnaire was administered to 40 female producers and 80 consumers, covering sociodemographic data, consumption patterns, the nature and origin of raw materials, storage conditions, and manufacturing processes. Mycotoxins and metals were analyzed using high-performance liquid chromatography coupled with tandem mass spectrometry (HPLC)/LC-MS/MS and atomic absorption spectrometry, respectively. The risk associated with exposure to chemical compounds was assessed by calculating the margin of exposure.

Results: Arsenic and lead were detected in all samples, with average concentrations of 205.1 ± 32.9 and 49.9 ± 6.7 µg/L, respectively. Aflatoxin B1 was quantified in 72.5% of the samples, with an average concentration of 3.20 µg/L. The margins of exposure were 0.032 for arsenic, 17.1 for aflatoxin B1, and 1.53 for lead. These margins of exposure values, which are below the threshold of 10,000 for aflatoxin B1 and arsenic, and 10 for lead, indicate a level of risk of concern for consumers. Prolonged consumption of tchapalo exposes consumers to risks of skin and liver cancer, as well as kidney damage.

Conclusion: A quality control plan for this beverage is necessary to ensure that consumers have access to safe food.

Keywords: Tchapalo, Sorghum, Toxicological risk, Aflatoxin B1, Arsenic, Lead, Côte d'Ivoire.

1 INTRODUCTION

Tchapalo is a traditional beer produced by the alcoholic fermentation of wort made from malts derived from various grains, such as sorghum, corn, and millet (Aka et al., 2017; Egounlety et al., 2019). It is one of the most widely consumed fermented beverages in West Africa, where it is also known by various names, including “dolo” in Burkina Faso and Mali and “pito” in Ghana and Nigeria (Ezekiel et al., 2018). In Côte d'Ivoire, this beverage, originally produced in the north of the country, has gradually spread throughout the entire country (Kouassi et al., 2024). Highly popular among the local population, tchapalo serves as an energy drink, a cultural product, and a source of income (Fokou et al., 2016; Palé et al., 2023). However, the grains used to produce this beer are substrates that are conducive to the growth of toxin-producing molds of the genera *Aspergillus*, *Fusarium*, and *Penicillium*. These molds produce various mycotoxins, such as aflatoxins, ochratoxin A, fumonisins, zearalenone, and deoxynivalenol (Nawaf, 2023; Adeyeye, 2020). Most of these mycotoxins are known for their carcinogenic, mutagenic, immunotoxic, and neurotoxic effects (El-Sayed et al., 2022; Hamad et al., 2023; Shekhar et al., 2025). Furthermore, these mycotoxins are resistant to heat treatments applied to grains (cooking, pasteurization, sterilization) (Gavahian et al., 2021; Iqbal et al., 2021; Mir et al., 2021). In addition to the risks associated with mycotoxins, tchapalo may also be contaminated by trace metals. These compounds, which are highly resistant to degradation, accumulate in the food chain from various sources of contamination (soil, the environment, and the manufacturing process). Grains can become contaminated with trace metals starting in the fields through environmental exposure or during the various stages of tchapalo production from water or the utensils used (Adepo et al., 2024; Scutarașu et al., 2023). Chronic exposure to these trace elements is associated with neurological, renal, hepatic, and cardiovascular damage, as well as carcinogenic effects (Shaheen et al., 2016; Annar et al., 2022). Mycotoxin contamination in cereal-based beverages has been reported in several studies around the world (Ezekiel et al., 2018; Schabo et al., 2021). In Côte d'Ivoire, research on tchapalo has focused primarily on its physicochemical properties, microbiological and organoleptic qualities, as well as its manufacturing processes (Amane et al., 2009; Amane et al., 2012; Attchelouwa et al., 2020; Coulibaly et al., 2021). To date, no study has documented the level of chemical contamination in Côte d'Ivoire. Thus, the objective of this study was to assess the toxicological risk associated with its regular consumption in the Abidjan district.

2 MATERIALS AND METHODS

2.1 Description of the Study Area

This study was conducted in four municipalities in the Autonomous District of Abidjan, the economic capital of Côte d'Ivoire, which had an estimated population of more than 6 million in 2021 (ANStat, 2023). These four municipalities (Abobo, Anyama, Koumassi, and Yopougon) were selected based on their high population density and the documented presence of female tchapalo producers and retail outlets (Fokou et al., 2016) (Figure 1). The climate of the study area is equatorial, with an average annual temperature of 26 °C and relative humidity ranging from 80 to 90 %.

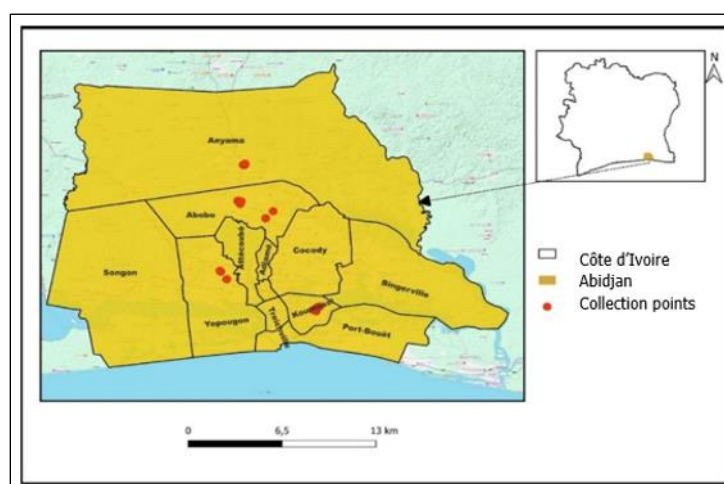


Figure 1: Study area

2.2 Sampling

A purposive sampling method was used to select production sites, with female producers and vendors identified through a preliminary survey. A total of 40 samples of tchapalo were collected from 40 female producers at 18

georeferenced sales locations, some of whom operate from the same location (Figure 2). These samples were collected in four municipalities in the Abidjan district. Specifically, 15 samples were collected in Abobo, 6 in Anyama, 9 in Koumassi, and 10 in Yopougon (Table 1). The collected samples were immediately transported to the laboratory in coolers. They were divided into two aliquots; the first (300 mL) was acidified with nitric acid (HNO₃) and stored at 4 °C until trace metal analysis. The second, untreated aliquot (300 mL) was stored directly at 4 °C for mycotoxin analysis. All analyses were performed at the ENVAL laboratory (Abidjan, Côte d'Ivoire), which is accredited under ISO/IEC 17025.



Figure 2: Tchapalo

2.3 Field Survey

Data were collected using a structured questionnaire administered to 40 female tchapalo producers and 80 consumers at the same locations where samples were collected. The questionnaire for female producers focused on the nature and origin of raw materials, storage conditions, production processes, types of utensils and containers, the quality of the water used, and hygiene conditions at the site. At the consumer level, sociodemographic data (age, sex, body weight), consumption, and smoking habits were collected (Table 1).

Table 1: Breakdown of producers and consumers by municipality

Localities	Producers	Consumers
Abobo	15	30
Anyama	6	12
Yopougon	10	20
Koumassi	9	18
Total	40	80

2.4 Analysis of physicochemical parameters

Four (4) physicochemical parameters were determined to characterize commercially available tchapalo. The alcohol content was determined using the hydrometer method in accordance with ISO 4801. The soluble dry residue was determined by refractometry in accordance with ISO 2173. Total acidity was determined by acid-base titration and expressed in milliequivalents per liter (meq/L). The pH was measured by direct potentiometry on the homogenized sample.

2.5 Contaminant analysis

2.5.1 Analysis of trace metals

Trace metals (As, Cd, Cr, Pb) were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES) and cold-vapor atomic absorption spectrometry (AAS) for mercury (Hg). The concentrations of trace metals were calculated from calibration curves, taking into account the dilution factor, the sample mass, and the analytical blank value.

2.5.2 Detection and quantification of mycotoxins

2.5.2.1 Extraction

A 5 mL sample of pre-homogenized tchapalo was placed in a centrifuge tube. Liquid-liquid extraction was performed by adding 10 mL of a solvent consisting of a water/acetonitrile mixture (50/50, v/v), acidified with 1% acetic acid. The mixture was then shaken on a rotary shaker at 30 revolutions per minute for 10 minutes to ensure optimal contact between the sample and the solvent. After shaking, the tubes were centrifuged at 4,000 revolutions per minute for 5 minutes to separate the phases. The supernatant was collected and then transferred to an injection vial for analysis.

2.5.2.2. Mycotoxin quantification

Mycotoxin quantification was performed using high-performance liquid chromatography coupled with tandem mass spectrometry (HPLC)/LC-MS/MS. An injection volume of 50 µl was used. A Phenomenex Kinetex 2.6 µm C18 100 Å reverse-phase column (50 x 2.1 mm ID), with a 2.1 mm ID C18 precolumn, was used at a temperature of 50 °C. The column was then pressurized to between 145 and 165 bars. The elution gradient had a flow rate of 0.4 mL/min. Mobile phase 1 was a 99.5/0.5 mixture of water and acetic acid, while mobile phase 2 was a 99.5/0.5 mixture of isopropanol and acetic acid. The detector was a Shimadzu LC-MS 8040, using electrospray ionization (ESI). Finally, the nebulizing gas flow rate was 2.5 µl/min and the drying gas flow rate was 15 µl/min.

2.6 Chemical risk assessment

The risk assessment was conducted according to the approach recommended by the FAO and WHO, which involves hazard identification, hazard characterization, exposure assessment, and risk characterization (FAO, 2009).

2.6.1 Identification and characterization of hazards

The characterization of hazards involved determining a toxicological reference value (TRV) for each contaminant identified in tchapalo. Each TRV was defined based on the benchmark dose (BMD), which corresponds to a dose that produces a measurable effect associated with a given response level relative to a control group. The selected TRV is the lower limit of the 95% confidence interval for the BMD (BMDL95%), that is, the dose associated with a given increase in the incidence of the critical effect (10% for BMDL10, 1% for BMDL01). The BMDLs were selected based on recent scientific data from the European Food Safety Authority (EFSA) (EFSA, 2010; 2020; 2024) (Table 2).

Table 2: Summary table of target margin of exposure

Contaminants	BMDL (µg/kg bw/day)	Critical effect selected	Interpretation of the MOE
Aflatoxin B1	(BMDL ₁₀) : 0,40	Liver Cancer	If MOE < 10,000: Cancer risk of concern
Inorganic Arsenic	(BMDL ₀₅) : 0,06	Skin Cancer	
Lead	(BMDL ₁₀) : 0,63	Kidney failure	If MOE < 10 : Risk of chronic kidney disease

BMDL: lower limit of the confidence interval for the benchmark dose; MOE: margin of exposure; bw: body weight.

2.6.2 Exposure assessment

The daily volume of tchapalo consumed (V) in liters per day (L/day) was calculated for each consumer based on the volume consumed per occasion (V_{occ}) and the weekly frequency of consumption (F): $V = (V_{occ} \times F) / 7$

The daily exposure dose (DED), expressed in µg/kg body weight/day, was then calculated individually for each of the 80 consumers:

- $DED = (C \times V) / P$
- C: concentration of the contaminant in the sample (µg/L);
- V: daily volume ingested (L/day);
- P: consumer's body weight (kg).

2.7 Risk characterization

Since the contaminants identified are substances with no dose threshold, the risk assessment was based on the calculation of the margin of exposure (MOE), which is the ratio of the BMDL to the daily exposure dose (DED). This approach helps indicate the level of risk concern (Table 2).

$$\text{MOE} = \text{BMDL} / \text{DJE}$$

- MOE: margin of exposure;
- BMDL: lower bound of the confidence interval for the benchmark dose ($\mu\text{g}/\text{kg bw}/\text{day}$);
- DED: daily exposure dose ($\mu\text{g}/\text{kg bw}/\text{day}$).

2.8 Statistical analysis

The data were entered into Microsoft Excel and analyzed using Python 3.12 (pandas, SciPy, statsmodels, scikit-posthocs). Qualitative variables are described by their frequencies and percentages; quantitative variables are described by the mean, standard deviation, median, extreme values, and the 95th percentile. The relationship between the volume consumed per occasion and the frequency of consumption was assessed using Spearman's correlation coefficient. Comparisons between municipalities were therefore conducted after aggregating data by collection point, using the Kruskal-Wallis test followed, where appropriate, by the Dunn test with Holm correction. Prevalences were compared using an exact permutation test (20,000 draws). The significance threshold was set at 5%.

3 RESULTS

3.1 Characteristics of the women producers

Figure 3 shows a very homogeneous sociodemographic profile of the 40 women tchapalo producers surveyed. All of them (100 %) have made the production and sale of tchapalo their primary occupation. The majority are over 45 years old (57.5 %), have been in the business for more than 10 years (92.5 %), but have no formal education (60 %).

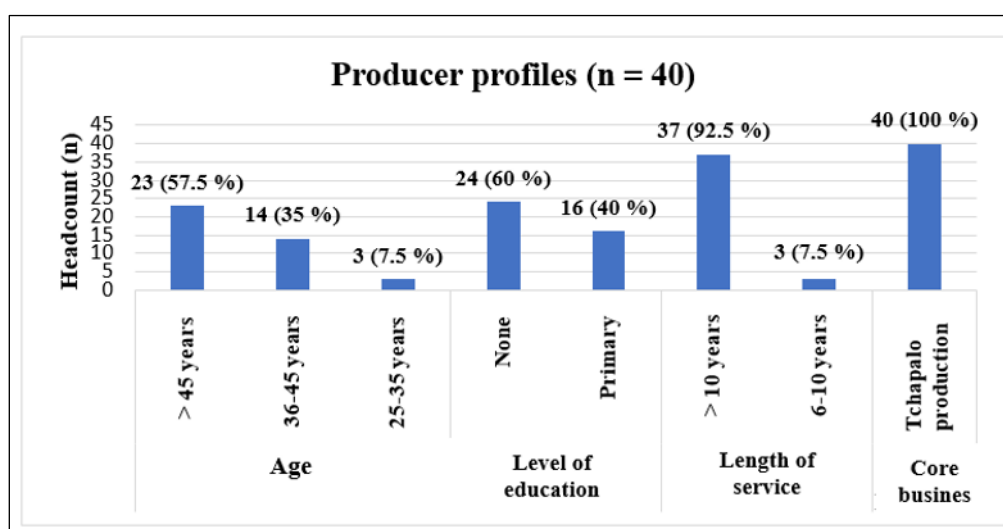


Figure 3: Socio-demographic Characteristics of Women Producers

3.2 Supply and production practices

Production practices and the environmental characteristics of the sites were surveyed and are presented in Table 3. Manufacturing relies on traditional processes, using only sorghum sourced from the local market (100 %). The grains are stored in facilities made of non-durable materials for one to two weeks. The floors of the premises are dirt floors with limited hygiene standards. The water used comes from the tap, without prior treatment, and the production equipment is mostly made of plastic (87.5%). The production environment remains exposed to sources of contamination such as dust and the presence of animals. Fermentation takes place indoors, followed by rapid sale (within 24 hours), with storage at room temperature in covered containers.

Table 3: Production practices and environmental conditions (n = 40)

Variable	Modality	Headcount (n)	Percentage (%)
Grain used	Sorghum	40	100
Source	Local Market	40	100
Storage method	Bag on the floor	40	100

Storage life	1–2 weeks	40	100
Roof of the room	Sheet metal	40	100
Wall of the room	Free	39	97.5
	Brick	1	2.5
Floor of the room	Earth	40	100
Floor Sweeping	Yes	40	100
Floor Cleaning	No	40	100
Floor Disinfection	No	40	100
Water source	Faucet	40	100
Water Treatment	None	40	100
Cleaning the Equipment	Before each production run	40	100
Presence of animals / dust on the site	Yes	40	100
Fermentation site	Interior	40	100
Pre-sale period	< 24 h	40	100
Storage Instructions	Ambient temperature	40	100
Container lid	Always	40	100,0

3.3 Consumer profile and habits

Table 4 highlights the sociodemographic characteristics and consumption habits of the 80 tchapalo consumers surveyed. The majority of consumers are male (91.25%), with a predominance of middle-aged adults, primarily between the ages of 41 and 50 (48.75%). More than half of the consumers (62.5%) report drinking more than 2 liters per occasion. Consumption is regular, with a majority (61.25%) consuming it on average once or twice a week. More than two-thirds (67.50%) report having consumed it for more than five years. In terms of consumption habits, a significant proportion (43.75%) drinks tchapalo on an empty stomach. Furthermore, more than one-third combines this drink with other traditional beverages. Finally, tobacco use remains marginal in this population, with only 3.75% of smokers.

Table 4: Profile and Consumption Habits (n = 80)

Variable	Modality	Headcount (n)	Percentage (%)
Sex	Male	73	91.25
	Feminine	7	8.75
Age (years)	41–50	39	48.75
	31–40	21	26.25
	> 50	18	22.5
	20–30	2	2.5
Average quantity per occasion (Liter)	> 2	50	62.5
	1–2	24	30
	0,5–1	4	5
	< 0,5	2	2.5
Frequency of consumption	1–2 times a week	49	61.25
	3–4 times a week	29	36.25
	5–7 times a week	1	1.25
	1–2 times per month	1	1.25

Length of time as a customer (years)	> 5 ans	54	67.5
	1–5	24	30
	< 1	2	2.5
Consumption of Other Traditional Beverages	No	51	63.75
	Yes	29	36.25
Smoker	No	77	96.25
	Yes	3	3.75

3.4 Physicochemical characterization

The physicochemical parameters of the analyzed tchapalo are presented in Table 5. The average alcohol content is 4.7%, while the average total acidity is 106 meq/L. The soluble dry residue is approximately 8%. Finally, the pH is acidic (≈ 4.1).

Table 5: Physicochemical Parameters of Tchapalo

Parameters	Mean $\pm$ standard deviation	Scope	CV (%)
Alcohol Content (%)	4.74 $\pm$ 0.6	4.18 – 5.37	12.6
Total acidity (meq/L)	105.67 $\pm$ 18.58	93 – 127	17.6
Soluble dry matter (%)	8.07 $\pm$ 1.45	6.4 – 9	17.9
pH	4.11 $\pm$ 0.05	4.06 – 4.16	1.2

3.5 Chemical contamination of tchapalo

3.5.1 Trace metal content

Table 6: Arsenic and lead concentrations in tchapalo ($\mu\text{g/L}$)

Contaminants	Sampling Area	Positive samples (n)	Mean $\pm$ standard deviation	Min.	Med.	Max.	p-value	Maximum content ($\mu\text{g/L}$)
Arsenic	Abobo	15 (100 %)	228.9 $\pm$ 23.98	174	226	274	0.0001	10
	Anyama	6 (100 %)	212.5 $\pm$ 32.27	168	219.5	246		
	Koumassi	9 (100 %)	198.1 $\pm$ 13.17	180	203	214		
	Yopougon	10 (100 %)	171.3 $\pm$ 27.35	145	161,5	210		
	Total	40 (100 %)	205.1 $\pm$ 32.85	145	209.5	274		
Lead	Abobo	15 (100 %)	52.47 $\pm$ 3.86	47.9	52	60.2	0.0407	200
	Anyama	6 (100 %)	47.50 $\pm$ 3.86	39.9	47.95	53.2		
	Koumassi	9 (100 %)	51.20 $\pm$ 9.74	42.7	46.4	73.4		
	Yopougon	10 (100 %)	46.49 $\pm$ 6.49	36.6	46.9	60.7		
	Total	40 (100 %)	49.95 $\pm$ 6.71	36.6	49.25	73.4		

*Maximum arsenic content in products placed on the market in liquid form, as established by Commission Regulation (EU) 2023/915 of April 25, 2023 **Maximum lead content in products placed on the market in liquid form, as established by Commission Regulation (EU) 2023/915 of April 25, 2023 Min: minimal; Max: maximum; Med: median

Table 6 presents the levels of trace metal contamination in tchapalo. Of the five metals tested for (As, Cd, Cr, Pb, Hg), only arsenic and lead were detected in the analyzed samples. All samples analyzed (100%) were contaminated with these two trace metals. The average concentrations of arsenic ranged from 171 $\mu\text{g/L}$ to 229 $\mu\text{g/L}$, with an overall average of 205 $\mu\text{g/L}$. Arsenic levels are significantly higher than the maximum limit of 10 $\mu\text{g/L}$ set by EU Regulation 2023/915 (EU, 2023). For lead, concentrations ranged from 46.49 $\pm$ 6.49 to 51.20 $\pm$ 9.74 $\mu\text{g/L}$, with an overall average of

50 µg/L. Lead levels comply with the recommended maximum limits of 200 µg/L. A significant difference was observed between the arsenic and lead levels in samples collected from the four municipalities ($p < 0.05$).

3.5.2 Mycotoxin content

Aflatoxins were detected in 72.5% of the tchapalo samples analyzed (Table 7). The average concentrations of aflatoxin B1 (AFB1) ranged from 2.78 µg/L to 3.71 µg/L, with an overall average of 3.20 µg/L. For total aflatoxins (TAFL), the averages ranged from 3.01 µg/L to 6.08 µg/L, with an overall average of 4.56 µg/L. The levels of AFB1 and TAFL are well above the maximum permissible levels, which are 2 µg/L and 4 µg/L, respectively. The differences in aflatoxin levels in tchapalo across municipalities are not statistically significant ($p > 0.05$).

Table 7: Aflatoxins levels in tchapalo (µg/L)

Contaminants	Sampling Area	Positive samples (n)	Mean $\pm$ standard deviation	Min.	Med.	Max.	p-value	Maximum content (µg/L)
Aflatoxin B1	Abobo	12 (80 %)	3.29 $\pm$ 0.53	2.26	3.36	3.99	0.0735	2*
	Anyama	6 (100 %)	3.01 $\pm$ 0.19	2.81	3	3.22		
	Koumassi	5 (55.6 %)	3.71 $\pm$ 1.64	2.80	3.04	6.63		
	Yopougon	6 (60 %)	2.78 $\pm$ 0.14	2.62	2.79	2.92		
	Total	29 (72.5 %)	3.20 $\pm$ 0.77	2.26	3.04	6.63		
Total aflatoxins	Abobo	12(80 %)	4.77 $\pm$ 1.47	2.26	5.40	6.33	0.5862	4**
	Anyama	6 (100 %)	3.01 $\pm$ 0.19	2.81	3	3.22		
	Koumassi	5 (55.6 %)	6.08 $\pm$ 6.94	2.80	3.04	18.50		
	Yopougon	6 (60 %)	4.43 $\pm$ 2.75	2.62	2.79	8.93		
	Total	29(72.5 %)	4.56 $\pm$ 3.17	2.26	3.12	18.50		

*Maximum level of aflatoxin B1 in cereal-derived products established by Commission Regulation (EU) 2023/915 of April 25, 2023 **Maximum level of total aflatoxins in cereal-derived products established by Commission Regulation (EU) 2023/915 of April 25, 2023 Min: minimal; Max: maximum; Med: median

3.6 Characterization of toxicological risk

3.6.1 Consumption level

The consumption parameters used in the calculation are shown in Table 8. The average daily volume ingested by consumers is 0.700 ± 0.440 L/day, with a median of 0.536 L/day and a range of 0.0123 to 2.14 L/day. The average body weight of consumers is 64.3 ± 5.6 kg, with a range of 50 to 78 kg.

Table 8: Consumer Exposure Parameters (n = 80)

Parameters	Mean $\pm$ standard deviation	Median	Scope
Daily beverage intake (L/day)	0.7 $\pm$ 0,44	0.536	0.0123 – 2.14
Body weight Consumers (kg)	64.3 $\pm$ 5.6	64	– 78

3.6.2 Daily exposure dose

The daily exposure doses (DEDs), obtained by matching each consumer to the samples collected at their location, are presented in Table 9. The average ADEs are 2.28 ± 1.51 , 0.547 ± 0.357 , and 0.036 ± 0.026 µg/kg bw/day for arsenic, lead, and aflatoxin B1, respectively.

Table 9: Individual daily exposure doses ($\mu\text{g}/\text{kg}$ body weight/day) (n = 80)

Contaminants	Mean $\pm$ standard deviation	Median	95th percentile
Arsenic	2.28 $\pm$ 1.51	1.86	5.21
Lead	0.547 $\pm$ 0.357	0.412	1.15
Aflatoxin B1	0.036 $\pm$ 0.026	0.023	0.081

3.6.3 Toxicological risk level associated with tchapalo consumption

The calculated marge of exposure (MOE) are well below 10,000 for arsenic and aflatoxin B1 and below 10 for lead. The health risk level for these three contaminants is considered a cause for concern. These results indicate that regular consumption of tchapalo exposes consumers to cancer risks (liver and skin cancer) from arsenic and aflatoxin B1, and to renal damage from lead (Table 10).

Table 10: Marge of exposure for contaminants in tchapalo

Contaminants	BMDL	MOE median	MOE at the 95th percentile	Interpretation
Inorganic arsenic	0.06	0.032	0,012 < 10 000	Skin Cancer: A Cause for Concern
Lead	0.63	1.53	0.55 < 10	Kidney damage: A level of risk that is cause for concern
Aflatoxin B1	0.40	17.1	4.9 < 10 000	Liver cancer: a concerning level of risk

4 DISCUSSION

Analysis of the physicochemical parameters of tchapalo shows that it is a low-alcohol beverage with an alcohol content of 4.74% (v/v), slightly acidic, with an average pH of 4.11 and a total acidity of 105.67 meq/L. The profile of this traditional beer, produced through spontaneous fermentation, is similar to those reported by various authors, who describe tchapalo as having an alcohol content of around 5% (v/v) and an acidic pH ranging from 3.3 to 4.1 (Amane et al., 2009; Aka et al., 2010). The low variation in the parameters studied from one locality to another reflects the high level of mastery of the brewing processes by the highly experienced female brewers. The tchapalo analyzed in this study was produced exclusively from sorghum. The chemicals considered in the risk assessment related to tchapalo consumption were mycotoxins and trace metals. These substances were selected based on data from the literature indicating a high probability of their presence in the food chain (Ezekiel et al., 2018; Kumar et al., 2020; Laura et al., 2023). Aflatoxins are the most toxic mycotoxins and have been proven to be carcinogenic in humans (IARC, 2012). They were tested for and detected in 72.5% of the samples analyzed. The average concentration of aflatoxin B1 (AFB1) was $3.20 \pm 0.77 \mu\text{g}/\text{L}$, and that of total aflatoxins (TAFL) reached $4.56 \pm 3.17 \mu\text{g}/\text{L}$. The levels of these mycotoxins were all higher than the maximum limits set for cereal-based products by Regulation (EU) 2023/915. The presence of aflatoxins in tchapalo is primarily linked to contamination of the sorghum used in its production. This grain provides a favorable environment for the growth of aflatoxin-producing molds. Aflatoxins are produced by molds of the genus *Aspergillus* (*A. flavus* and *A. parasiticus*), which colonize foodstuffs primarily during storage and preservation (Probst et al., 2014; Benkerroum, 2020). Furthermore, studies conducted in the subregion particularly in Benin, have isolated *A. flavus* and *A. parasiticus* in 15% and 8% of the sorghum samples analyzed, respectively (Tovide et al., 2018). Other authors have also reported the presence of aflatoxins in sorghum at levels ranging from $2.64 \pm 0.94 \mu\text{g}/\text{kg}$ (Niyuhire, 2023). In this study, sorghum is stored in a very unhygienic environment for one to two weeks. In fact, during this period, the bags of sorghum are placed directly on the floor which is often unpaved in areas that are not cleaned regularly (Fokou et al., 2016). These practices promote fungal contamination, given that *Aspergillus flavus*, which produces aflatoxins, lives in the soil (Frisvad et al., 2019; Probst et al., 2014). The preparation of tchapalo involves a series of steps: soaking, sprouting, drying, cooking, and fermentation (Amane et al., 2012). Aflatoxin contamination can also occur at these various stages of beer production. The sorghum is soaked for 72 hours, followed by 3 to 4 days of sun-drying, often on a tarp laid on the ground. During these stages, the temperature, humidity, and water activity are conducive to fungal growth. These results are supported by studies conducted on sorghum grains, malts, and the beers produced from them. The results revealed that all of the malts and beers were contaminated with total aflatoxins at average levels of $408 \pm 68 \mu\text{g}/\text{kg}$ and $22.32 \mu\text{g}/\text{L}$, respectively, whereas only 15% of the sorghum grains used contained these mycotoxins at an average concentration of $3.0 \mu\text{g}/\text{kg}$ (Matumba et al., 2011). These results suggest significant aflatoxin contamination during the various stages of tchapalo preparation. Aflatoxin contamination of traditional sorghum-based beers has been reported in various countries in the subregion, particularly in Burkina Faso, Mali, and Niger, where this beverage is very

popular among the local populations (Ezekiel et al., 2018; Matumba et al., 2011). Tchapalo is produced by boiling the filtrates from the mashing of sorghum malt flour for 5 to 6 hours (Amane et al., 2005; Aka et al., 2008). The presence of aflatoxins in this beverage clearly demonstrates their resistance to heat treatment. In fact, researchers have reported that these mycotoxins are highly stable and capable of withstanding temperatures of 250 °C (Azam et al., 2021; Liu, 2020). With regard to trace metals, only lead and arsenic were detected in all samples (100 %) analyzed, with average concentrations of 49.9 µg/L and 205.1 µg/L, respectively. The lead levels are within normal limits, while the arsenic levels are significantly higher than the regulatory limits set for products marketed in liquid form by Regulation (EU) 2023/915. The presence of these trace metals in all samples collected from various municipalities indicates environmental contamination of the sorghum originating from the fields where it is grown. These substances present in the environment can contaminate and accumulate in sorghum during its cultivation (Laura et al., 2023; Abdulla et al., 2025). Furthermore, the use of arsenic-based pesticides and fertilizers can exacerbate this contamination. Several studies show that commercially available grains can accumulate arsenic and lead from the field through to final storage (Kumar et al., 2020; Ahmad et al., 2026). The presence of lead in tchapalo may also be linked to contaminated water and metal utensils used during the production process of this traditional beer. Studies have found lead contamination in drinking water (Adepo et al., 2024). The substances found in tchapalo, such as aflatoxin B1 and arsenic, are known to have genotoxic carcinogenic effects in humans, while lead affects the nervous, cardiovascular, reproductive, hematological, and renal systems (EFSA, 2020; 2024). The health risk associated with tchapalo consumption was assessed by calculating the margin of exposure (MOE). This approach is appropriate for assessing the risks associated with substances that have no dose threshold, such as aflatoxin B1, arsenic, and lead. In this study, total arsenic was treated as inorganic arsenic for risk characterization. The exposure margins calculated based on the benchmark dose (BMD) and daily exposure doses were 0.032 for total arsenic, 17.1 for aflatoxin B1, and 1.53 for lead. These MOE values, which are below the threshold of 10,000 for aflatoxin B1 and arsenic, and below 10 for lead, indicate a level of risk of concern for consumers. Tchapalo is one of the traditional beverages consumed in Côte d'Ivoire, primarily by low-income social classes (Aka et al., 2017). Thus, prolonged consumption of tchapalo exposes consumers to risks of skin and liver cancer, caused by arsenic and aflatoxin B1, respectively. In addition, exposure to lead can cause kidney damage in consumers. Consequently, tchapalo a culturally cherished and widely consumed beverage, can be a major source of contamination, the long-term effects of which remain a significant cause for concern.

5 CONCLUSION

This study assessed the level of chemical risk associated with the consumption of tchapalo, a traditional beer widely consumed in Côte d'Ivoire. The substances identified in this beverage were aflatoxins, lead, and arsenic. The levels of aflatoxins and arsenic were significantly higher than regulatory limits. The health risk associated with regular consumption of this beverage, which is highly popular among the population, is considered a cause for concern. The toxic effects associated with this exposure can result in cancer and kidney disease. It is therefore essential to launch awareness and training campaigns for female producers who generally have no formal education on proper hygiene practices. A quality control plan for this beverage is also necessary to ensure that consumers have access to safe food.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Acknowledgments

We would like to thank the ENVAL laboratory for its support in conducting this study.

Disclosure of conflict of interest

The authors declared no conflict of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study

Authors contribution

Aholia Jean-Baptiste Adepo : writing ; Golou N'da Fidel N'guessan : execution ; Jean Di-Maïssou : execution ; Pierre Manda : project design ; Kouakou Brou : Editing and corrections ; Sébastien Dano Djédjé : supervision

REFERENCES

- [1] Abdulla, H.A., Al-Ghouti, M.A., Soubra, L., (2025). Arsenic contamination in rice: a DPSIR analysis with a focus on top rice producers. *Sci Total Environ*, 978, 179425. <https://doi.org/10.1016/j.scitotenv.2025.179425>.

- [2] Adepo, A.J.B., Manda, P., Akouaba, B.E. (2024). Quality Of Drinking Water In An Area With High Gold Panning Activity In Côte d'Ivoire (Daloa, Centre-West). (2024). IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT), 18(9) 2, 34-39. <https://doi.org/10.9790/2402-1809023439>
- [3] Adeyeye, A.O.S. (2020). Aflatoxigenic fungi and mycotoxins in food: a review. *Critical Reviews in Food Science and Nutrition*, 60(5), 709–721. <https://doi.org/10.1080/10408398.2018.1548429>
- [4] Ahmad, M.F., Ahmad, F.A., Zeyaulah, M., Bantun, F., Babalghith A.O., Ghaith, M.M., et al. (2026). Heavy metals in food: mechanisms of toxicity and migration through various routes in different foods. *Gondwana Research*, 154, 258-273. <https://doi.org/10.1016/j.gr.2025.12.021>
- [5] Aka, S., Fokou, G., Doumbia, M., Ahoussi J.M. S., Bonfoh, B. (2017). Production and consumption of tchapalo in Abidjan : A typology of brewers and consumers. *European Scientific Journal*, ESJ, 13(1), 148. <https://doi.org/10.19044/esj.2017.v13n1p148>
- [6] Aka, S., Djeni, N., N'guessan, K., Yao, K., Djè, K. (2010). Variability of biochemical and microbiological properties of tchapalo, a traditional sorghum beer in Côte d'Ivoire. *Afr Sci*, 4(2). <https://doi.org/10.4314/afsci.v4i2.61688>
- [7] Aka, S., Djeni, N.T., N'guessan, K.F., Yao, K.C., Dje, K.M. (2008). Variability of biochemical and microbiological properties of tchapalo, a traditional sorghum beer in Côte d'Ivoire. *Afrique Science*, 04(2), 274 – 286. <https://doi.org/10.4314/afsci.v4i2.61688>
- [8] Aka, S., Djè, K.M., Fokou, G., Doumbia, M., Ahoussi, J.M.S., Bonfoh, B. (2017). Production and Consumption of Tchapalo in Abidjan: A Typology of Brewers and Consumers. *Eur Sci J*. 13(1):148. <https://doi.org/10.19044/esj.2017.v13n1p148>
- [9] Amane, N.D., Assidjo, N.E., Gbongue, M.A., Bohoussou, K., Cardot, P., (2005). Physico-chemical characterisation of awest african traditional beer : the tchapalo. *Agronomie Africaine* 17 (2) : 143-152
- [10] Amane, D.N., Kouamé, K.B., Kouamé, C., Assidjo, E.N. (2012). Optimization of the process of manufacture of the tchapalo, traditional beer of the Ivory Coast by the fractional factorial plan. *Afr Sci*. 8(3), 69–81.
- [11] Amane, N., Assidjo, N., Gbongue, M., Bohoussou, K., Cardot, P. (2009). Physico-chemical characterisation of a west african traditional beer : the tchapalo. *Agron Afr*, 17(2), 143–52. <https://doi.org/10.4314/aga.v17i2.1665>
- [12] Annar, S. (2022). The characteristics, toxicity and effects of heavy metals arsenic, mercury and cadmium: a review. *International journal of multidisciplinary educational research*, 11, (4)3, 35-43. <http://ijmer.in.doi./2022/11.04.49>
- [13] ANStat (National Statistics Agency), (2021). General Population and Housing Census (RGPH). Abidjan, Cote d'Ivoire. available at : <https://www.anstat.ci>
- [14] Attchelouwa, C.K., N'guessan, F.K., Marcotte, S., Amoikon, T.L.S., Charmel, M., Djè, M.K. (2020). Characterisation of volatile compounds associated to sensory changes during the storage of traditional sorghum beer by HS-GC/FID and SPME-GC/MS. *J Agric Food Res*, 2, 100088. <https://doi.org/10.1016/j.jafr.2020.100088>
- [15] Azam, M.S., Ahmed, S., Islam, M.N., Maitra, P., Islam, M.M., Yu, D. (2021). Critical Assessment of Mycotoxins in Beverages and Their Control Measures. *Toxins (Basel)*, 13(5), 323. <https://doi.org/10.3390/toxins13050323>.
- [16] Benkerroum, N., (2020). Aflatoxins: Producing-Molds, Structure, Health Issues and Incidence in Southeast Asian and Sub-Saharan African Countries. *Int J Environ Res Public Health*, 17(4), 1215. <https://doi.org/10.3390/ijerph17041215>
- [17] Commission Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing Regulation (EC) No 1881/2006. *Official Journal of the European Union*. 119, 5.5.2023, pp. 103–157. <http://data.europa.eu/eli/reg/2023/915/oj>
- [18] Coulibaly, W.H., Bouatenin, K.M.J.P., Boli, Z.B.I.A., Camara, F., Sanogo, Y.M., Akissi, D.M, et al. (2021). Volatile compounds of traditional sorghum beer (tchapalo) produced in Côte d'Ivoire : comparison between wild yeasts and pure culture of *Saccharomyces cerevisiae*. *World J Microbiol Biotechnol*, 37(5), 75. <https://doi.org/10.1007/s11274-021-03026-1>
- [19] EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain), Schrenk, D., Bignami, M., Bodin, L., Chipman, J.K., del Mazo, J, et al. (2024). Update of the risk assessment of inorganic arsenic in food. *EFSA J*, 22(1), e8488. <https://doi.org/10.2903/j.efsa.2024.8488>
- [20] EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain), Schrenk, D., Bignami, M., Bodin, L., Chipman, J.K., del Mazo, J., Grasl-Kraupp, B., Hogstrand, C., (2020). Scientific opinion- Riskassessment of aflatoxins in food. *EFSA Journal*, 18(3), 6040. pp 112. <https://doi.org/10.2903/j.efsa.2020.6040>.

- [21] EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain). Scientific Opinion on Lead in Food. EFSA J 2010;8. <https://doi.org/10.2903/j.efsa.2010.1570>.
- [22] Egounlety, A. M., Viera-Dalode, G., Houssou, P., & Dossou, J. (2019). Processing, Microbiological, physicochemical and sensory characteristics of Chakpalo, Traditional maize beer from West Africa. *Ann. UP, Série Sci. Nat. Agron*, 9(2), 61–78. <https://doi.org/10.56109/aup-sna.v9i2.55>
- [23] El-Sayed, R.A., Jebur, A.B., Kang w., El-Demerdash, F. (2022). An overview on the major mycotoxins in food products: Characteristics, toxicity, and analysis. *Journal of Future, Foods*, 2(2), 91–102. <https://doi.org/10.1016/j.jfutfo.2022.03.002>
- [24] Ezekiel, C.N., Ayeni, K.I., Misihairabgwi, J.M., Somorin, Y.M., Chibuzor-Onyema, I.E., Oyedele, O.A., Abia, W.A., Sulyok, M., Shephard, G.S. and Krska, R. (2018). Traditionally Processed Beverages in Africa: A Review of the Mycotoxin Occurrence Patterns and Exposure Assessment. *Comprehensive Reviews in Food Science and Food Safety*, 17: 334-351. <https://doi.org/10.1111/1541-4337.12329>
- [25] Fokou, G., Doumbia, M., Aka, S., Ahoussi, J.M.S., Yapo, A.E., Djè, M.K., Bassirou Bonfoh, B. (2016). Identification and characterization of tchapalo production areas in Abidjan. *Int J Innov Appl Stud*, 18(4), 1167-1176
- [26] Food and Agriculture Organization of the United Nations (FAO), World Health Organization (WHO). (2009). Principles and methods for the risk assessment of chemicals in food. Geneva : World Health Organization. Environmental Health Criteria, 240. P752. <https://iris.who.int/server/api/core/bitstreams/e231a324-564f-4751-9272-ce786c1bcaff/content>
- [27] Frisvad, J.C., Hubka, V., Ezekiel, C.N., Hong, S.B., Nováková, A., Chen, A.J., et al. (2019). Taxonomy of *Aspergillus* section *Flavi* and their production of aflatoxins, ochratoxins and other mycotoxins. *Stud Mycol*, 93, 1-63. <https://doi.org/10.1016/j.simyco.2018.06.001>.
- [28] Gavahian, M., Mathad, G.N., Oliveira, C.A.F., Khaneghah M.A. (2021). Combinations of emerging technologies with fermentation : Interaction effects for detoxification of mycotoxins? *Food Res Int*, 141:110104. <https://doi.org/10.1016/j.foodres.2021.110104>.
- [29] Hamad, G.M., Mehany, T., Simal-Gandara, J., Abou-Alella, S., O.J. Esua, M. A. Abdel-Wahhab, E.E. Hafez. (2023). A review of recent innovative strategies for controlling mycotoxins in foods, *Food Contol*, 144, 109350, 1-11. <https://doi.org/10.1016/j.foodcont.2022.109350>
- [30] IARC, (2012) Aflatoxins. In: IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, Eds., IARC Monographs on the Evaluation of Carcinogenic Risks to Humans: Vol. 100F. Chemical Agents and Related Occupations, International Agency for Research on Cancer, Lyon, 225-248.
- [31] Iqbal, S.Z., Abdull Razis, A.F., Usman, S., Ali, N.B., Asi, M.R. (2021). Variation of Deoxynivalenol Levels in Corn and Its Products Available in Retail Markets of Punjab, Pakistan, and Estimation of Risk Assessment. *Toxins (Basel)*, 13(5), 296. <https://doi.org/10.3390/toxins13050296>.
- [32] Kouassi, A.T., Blei, S.H., Boko, A.C.E., Angaman, D.M. (2024). Traditional fermented foods from Côte d'Ivoire: knowledge, consumption and production methods in five localities surveyed. *Int J Gastron Food Sci*. 37:101002. <https://doi.org/10.1016/j.ijgfs.2024.101002>
- [33] Kumar, A., Cabral-Pinto, M.M.S., Chaturvedi, AK, Shabnam, A.A., Subrahmanyam, G., Mondal, R. et al., (2020). Lead Toxicity: Health Hazards, Influence on Food Chain, and Sustainable Remediation Approaches. *Int J Environ Res Public Health*, 17(7), 2179. <https://doi.org/10.3390/ijerph17072179>.
- [34] Laura, S., Maïga-Yaleu, S.B., Ramdé, T. (2023) Investigation of Pollution Level of Traces Metals Elements in Agricultural Soil of Oubritenga Province of Burkina Faso. *Open Journal of Soil Science*, 13, 187-198. <https://doi.org/10.4236/ojss.2023.133008>
- [35] Liu, Y., Galani, Y.J.H., Gong, Y.Y., Orfila, C., (2020). A review of postharvest approaches to reduce fungal and mycotoxin contamination of foods. *Compr. Rev. Food Sci. Food Saf*, 19:1521-1560. <https://doi.org/10.1111/1541-4337.12562>.
- [36] Matumba, L., Monjerezi, M., Khonga, E.B., Lakudzala, D.D. (2011). Aflatoxins in sorghum, sorghum malt and traditional opaque beer in southern Malawi. *Food Control*, 22, 266–8. <https://doi.org/10.1016/j.foodcont.2010.07.008>.
- [37] Mir, S.A., Dar, B.N., Shah, M.A., Sofi, S.A., Hamdani, A.M., Oliveira, C.A., Sant'Ana, A.S., (2021). Application of new technologies in decontamination of mycotoxins in cereal grains : challenges, and perspectives. *Food Chem. Toxicol*. 148, 111976. <https://doi.org/10.1016/j.fct.2021.111976>
- [38] Nawaf, A. (2023). Mycotoxin source and its exposure causing mycotoxicoses. *Bioinformation*, 19(4), 348-357. <https://doi.org/10.6026/97320630019348>.

- [39] Niyuhire, B. (2023). Contribution to the Study of White Sorghum Quality in Burundi: Assessment of Aflatoxin Contamination. Master's Thesis in Food Science and Technology, University of Burundi. P40. <https://repository.ub.edu.bi/handle/123456789/1555>
- [40] Palé, O.N., Ehui, P.J. (2023). Sociocultural factors of the monopolization of the production and marketing of tchapalo by the Lobi woman in Agnibilékrou (Ivory Coast). *Pensées Genre. Penser Autrement*, 3(1), 67–80.
- [41] Probst, C., Bandyopadhyay, R., Cotty, P.J., (2014). Diversity of aflatoxin-producing fungi and their impact on food safety in sub-Saharan Africa. *Int J Food Microbiol*, 174, 113–22. <https://doi.org/10.1016/j.ijfoodmicro.2013.12.010>.
- [42] Schabo, D.C., Alvarenga, V.O., Schaffner, D.W., Magnani, M. (2021). A worldwide systematic review, meta-analysis, and health risk assessment study of mycotoxins in beers. *Compr Rev Food Sci Food Saf*, 20(6), 5742–64. <https://doi.org/10.1111/1541-4337.12856>
- [43] Scutarașu, E., Trincă, L. (2023). Heavy metals in foods and beverages: global situation, health risks and reduction methods. *Foods*. 12(18):3340. <https://doi.org/10.3390/foods12183340>.
- [44] Shekhar, R., Raghavendra. V.B., Rachitha, P. (2025). A comprehensive review of mycotoxins, their toxicity, and innovative detoxification methods. *Toxicol Rep*, 14, 101952. <https://doi.org/10.1016/j.toxrep.2025.101952>
- [45] Shaheen, N., Ahmed, M., Islam, M., Habibullah Al Mamun, M., Tukun, A.B., Islam, S.M.A., Rahim, A.T. (2016). Health risk assessment of trace elements via dietary intake of 'non piscine protein source' foodstuffs (meat, milk and egg) in Bangladesh. *Environ Sci Pollut Res*, 23(8), 7794–806. <https://doi.org/10.1007/s11356-015-6013-2>
- [46] J Tovide, N., Adéoti, K., Noumavo, P, A., Garba, K., Ohin, B., Soninhekpon, A., Fidèle Tchobo, F. et al., (2018). Occurrence of Molds and Identification of Mycoflora Contaminating Millet and Sorghum Produced and Consumed in Benin. *Int. J. Curr. Microbiol. App. Sci*, 7(9): 3750-3763. <https://doi.org/10.20546/ijcmas.2018.709.464>