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Research Article

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Posted Date: October 12th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10805282/v1

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Additional Declarations: No competing interests reported.

HACCP-based determination of critical control points during frying by street deep-fried meat vendors and assessment of dietary exposure to malondialdehyde

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Abstract

This work aimed to apply Hazard Analysis and Critical Control Point (HACCP) principles during the frying process by street deep-fried meat vendors, and evaluate the potential health risks associated with dietary exposure to malondialdehyde. A survey based on the FAO/WHO Guidelines for food hygiene and a pre-validated checklist based on HACCP principles revealed widespread non-compliance with food hygiene standards and frying practices. An analysis of the chemical quality of the collected meat fats showed that 83 % exceeded the thiobarbituric acid (TBA) threshold, indicating high levels of malondialdehyde (MDA). Microbial tests found unacceptable levels of *Staphylococcus spp*. in 43.3% of samples, mesophilic bacteria in 63.3% of samples, and *Salmonella spp.* in 6.7% of samples. HACCP analysis showed that control is essential to prevent, eliminate, or reduce a health hazard during three key stages (meat display, frying, and service) of the fried pork production process. HACCP-based corrective actions include using enclosed display cases, limiting frying cycles, employing monounsaturated oils, and improving hygiene practices. The daily dietary exposure to malondialdehyde for consumers was calculated to assess the safety and risks. Out of 30 fried meat samples, 9 (30%) had daily MDA intake levels that surpassed the maximum limit of 30 µg/kg body weight per day. These samples pose a risk to consumers' health and should not be consumed. The findings highlight significant microbial and chemical hazards associated with street-fried meats, underscoring the urgent need for regulatory oversight and vendor awareness-raising to safeguard public health.

Keywords : street deep-fried meat, HACCP analysis, malondialdehyde exposure, microbial contamination, frying oil degradation.

1. Introduction

Ready-to-eat foods sold on the streets are becoming increasingly popular and play a vital role in the nutrition of millions of people in urban areas of developing countries (Alimi et al., 2014; FAO, 2020). Street food not only comes at budget-friendly prices but also attracts city dwellers with its delicious flavors, a testament to the culinary skills of the vendors (Choudhury et al., 2011 ; Alimi et al., 2016). In Cameroon, rapid urbanisation, socio-economic constraints and the nutritional transition have increased dependence on these foods, particularly fried meats (Womeni, 2018). In this country, the preparation and sale of fried meats typically operate beyond the reach of regulatory oversight. Street vendors selling deep-fried meats have equally popped up all over the place, which has raised concerns among public authorities about the safety and quality of the food being offered (Kaptso et al., 2021).

Recently, Tampa et al. (2025) assessed the food hygiene and frying practices of unlicensed street meat vendors in West Cameroon. The findings indicate that 95% of vendors are not following the recommended guidelines for frying cycles, potentially leading to the production of harmful oxidation products in the fried meats. Futhermore, over 75% of these vendors fail to adhere to essential food hygiene practices. Alarmingly, 92.50% handle both money and meat, increasing the risk of foodborne illnesses. Access to running water is limited, with less than 20% of vendors having it available ; more than 80% depend on boreholes and wells, which could be contaminated with various pollutants and fecal microbes. In a study conducted by Teboukeu et al. (2025), samples of frying oils collected from vendors in North-West Cameroon revealed alarmingly high levels of degradation. The analysis indicated that adehyde levels were found to be 3 to 4 times above standard limits in most samples. This raises serious health concerns, as meat cooked in such oxidized oil tends to absorb not only the oil itself but also harmful compounds (Chang et al., 2020). These previous studies show that the situation is worrying and alarming because these fried foods continue to be a nutritional source for many people. It is therefore important to continue investigations to identify and control the hazards that occur throughout the fried meat preparation process. It is also important to measure the health risk to consumers of these meats.

The Hazard Analysis Critical Control Point (HACCP) has been recognized as a more effective food quality control strategy than the conventional end-product sampling practices, because it places more emphasis on prevention and control of potential hazards (FAO, 2004). This tool can therefore be useful for diagnosing the handling of raw meat, the management of frying oil, the frying process itself, and the service after frying (hazards can appear before or after frying). All of this would therefore help identify the critical control points essential for

preventing, reducing, or eliminating hazards in the production chain of ready-to-eat fried meats. Exposure to oxidation products, particularly malondialdehyde (MDA), produced during repeated frying, can pose a health risk in case of frequent consumption (Papastergiadis et al., 2014). Several studies have shown the potential toxicity of MDA in biological systems due to its high reactivity with proteins and DNA (Esterbauer et al., 1991; Uchida, 2003; Guillen and Goicoechea, 2008; Voulgaridou et al., 2011).

This study focused on implementing HACCP principles to identify and evaluate critical control points in the frying processes used by street deep-fried meat vendors. It also aims to assess the potential health risks linked to dietary exposure to malondialdehyde.

2. Material and methods

2.1 Study Area

This study was conducted in the Bamenda II and Bamenda III subdivisions of Bamenda city in the North-West Region of Cameroon. These urban areas have a high population density and are recognized for their vibrant street food culture, particularly in the sale of deep-fried meats, such as pork. The selection of these subdivisions was based on their high density of vendors operating roadside food stalls or open frying spots, significant consumer traffic, and the lack of structured hygiene monitoring.

2.2 Study population

The study employed the convenience sampling technique. Street vendors engaged in the frying and sale of pork were selected based on their physical presence, willingness to participate, and accessibility at the time of the researcher's visits to the field. A total of 30 vendors were selected for this study.

2.3 Establishment of a detailed preparation diagram and determination of critical control points

2.3.1 Observation and collection of qualitative data

The observation of the preparation process and the collection of qualitative data were carried out by two Master's students in Nutrition, Food and Bioresource Technology at the University of Bamenda, Cameroon. Before data collection, both the M.Sc. supervisors and the students established the process to be followed. A pre-test was conducted to ensure the reliability of the results.

A pre-validated checklist based on HACCP (Hazard Analysis and Critical Control Points) principles was used as a guide during the field observations. The decision tree developed by

the Codex Alimentarius Commission (2009) on food hygiene also helped in drawing up the checklist.

Data were also gathered through an interviewer-administered questionnaire. This questionnaire was crafted based on the FAO/WHO principles and guidelines for food hygiene and safety (FAO, 2009) as well as insights from previous studies (Tampa et al., 2025; Teboukeu et al., 2025). The interview was held face-to-face to ensure greater accuracy and thoroughness. The primary variables studied included the display of meat, the type of frying oil used, frying duration with the same oil, the frequency of changing frying oil, frying temperature, oil filtration processes, and the cleanliness of serving utensils. Additionally, food hygiene were evaluated using the following indicators : the source of water for boiling meat, the source of water for washing service equipment and kitchen tools, methods for washing and rinsing utensils, handwashing after financial transactions, how often the water for washing utensils was changed, how often the water for rinsing utensils was changed, the cleanliness of the clothing worn by vendors, the use of hair protection during food preparation and sales, and the wearing of aprons during these activities.

2.3.2 Collection of meat samples for quantitative analysis

The quantitative data were also used to identify potential CCPs (Critical Control Points) and assess vendors' compliance with basic food safety protocols.

A sample of meat (pork) weighing approximately 80 g was collected from each of the vendors directly after frying. Each sample was stored in sterile containers. Samples were labeled with a unique code to ensure traceability. The fat was extracted from each sample of fried meat in order to quantify the free fatty acids and oxidation products.

During service to customers, approximately 80 g of ready-to-eat fried meat was also taken as individual samples and stored under the same conditions as described above. These samples were used for microbiological analysis.

2.3.3 Chemical characterization of fats extracted from meats

Fat was extracted from raw meat (fresh pork) and fried meats using the technique outlined by Bligh and Dyer (1959), which involves a combination of chloroform and methanol in a 2:1 ratio. The extracted fat samples were subsequently stored at – 4°C for analysis.

Free fatty acids, the preferred substrate for oxidation, were evaluated using the AOCS official method Ca 5a-40 (American Oil Chemists' Society AOCS, 2003). The thiobarbituric acid (TBA) test was carried out according to the method described by Draper and Hadley (1990) to quantify oxidation products (malondialdehyde).

2.3.4 Microbial analysis of ready-to-eat fried meats

Samples of ready-to-eat fried meat were analyzed to detect and quantify bacteria and coliforms. Briefly, 35 g of each sample was weighed in a sterile manner and diluted into a conical flask filling with 315 ml of buffered peptone water (Hameau, Germany). The mixture was then homogenized. Folllowing this, we prepared serial dilutions (10^{-1}-10^{-4}) according to ISO 6887-1 (2017).

For analysis, we employed conventional culture methods using selective and differential media.

Determination of the total mesophilic aerobic bacteria (TMAB) was carried out using the pour plate method as outlined in NF ISO 4833-1 (2013). A volume of 100 µl of each sample was spread onto 12.5 ml Plate Count Agar (PCA; LiofilChem, Italy**)** placed in Petri dishes, wich were incubated at a temperature of 30±1 °C for 48 hours under aerobic conditions.

For total coliform detection according to the method described in NF ISO 4832 (2006), 100 µl of diluted samples were spread on the surface of sterilized 12.5 ml MacConkey Agar (MCA; LiofilChem, Italy) and incubated at 37°C for 24 hours. Any milky white colonies that developed on the surface of the Petri dishes were identified as coliforms.

The presence of *Salmonella* spp. in fried meats was determined using the method proposed by ISO 6579-1 (2017). For isolation of *Salmonella* spp., we inoculated 100 µl of the samples onto Salmonella and Shigella Agar (SSA; Himedia, India), and incubated them for 18 to 24 hours at 37 °C. Uncoloured colonies with black centers were identified as *Salmonella* spp.

The ISO 6888-1 (2021) method was used for the enumeration of *Staphylococcus* spp. We inoculated 100 µl of each dilution onto a 12.5 ml Mannitol Salt Agar (MSA; LiofilChem, Italy). The white colonies that appeared on the MSA were counted as *Staphylococcus* spp.

After the incubation periods, we counted the individual colonies on the Petri dishes. The average results from the duplicates were reported as log Colony Forming Units (CFU)/g.

2.4 Estimation of dietary exposure to malondialdehyde

The daily dietary exposure to malondialdehyde (DDEM) for consumers was calculated to assess the safety and risks. The European Food Safety Authority (EFSA) Scientific Committee (2011) suggests a maximum exposure limit of 30 µg/kg body weight/day for malondialdehyde. The following equation was used:

$$\text{DDEM} = \frac{\text{Food consumption} \times \text{MDA concentration}}{\text{Body weight}}$$

Food consumption refers to the daily intake of pork per group, measured in gram/Adult Male Equivalent each day. In previous research by Ingenbleek et al. (2017), the estimated daily pork consumption in Cameroon was reported at 0.6 g/AME/day. This study spanned multiple African countries and was grounded in the analysis of food expenditure data gathered from national household budget surveys provided by each country's national statistical institutes.

The concentration of MDA was calculated for each meat sample as described above through the determination of the TBA value (Figure 3) and expressed in µg/kg.

Thetypical weight for an adult is around 70 kg.

2.5 Statistical analysis

Data were coded and checked for completeness. Data entry and analysis were performed using Epi InfoTM version 7.2.6.0. Descriptive statistics were presented as frequencies and percentages. The red lines shown in the various graphs indicate the standard thresholds and enable the quality of the analysed samples to be assessed.

3. Results and discussion

3.1 Description of the fried meat process

Figure 1 presents the production chain of fried meat up to the consumer's table. Once the raw meat is obtained, it is cut and boiled by adding ingredients (Maggi cube®, cooking salt, spices) that vary from one vendor to another and according to the desired taste and colour. The boiled pieces of meat are then displayed for consumers to choose from. The pieces chosen by the consumer are cut into smaller sizes before being plunged into hot oil. Deep frying in the pan or in traditional deep-fryers is practiced by all vendors and is stopped when the pieces of meat tend to be crispy. Fried meat is served on plates that have been previously washed or wiped. It is often accompanied by ingredients (Maggi cube®, pepper, spices) according to the consumers' preferences. Consumers use toothpicks to easily grab and enjoy ready-to-eat pieces of meat.

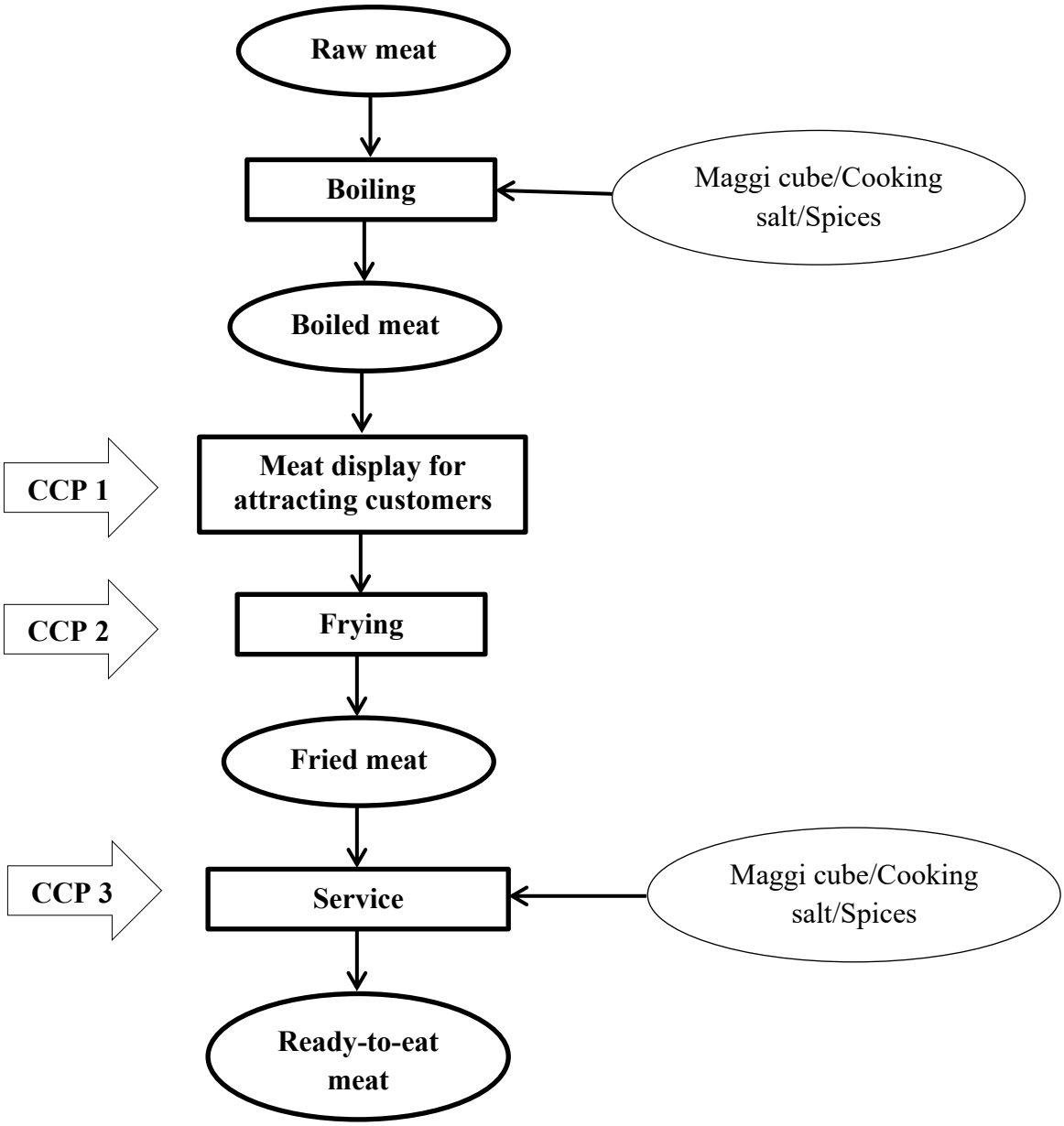


Figure 1. Flow diagram showing the frying meat process

3.2 Hazard analysis during the preparation and service of the fried meat

3.2.1 Frying practices and overall food hygiene conditions

Table 1 shows the conditions and frying practices among the vendors. It is noted that before frying, 76.7% of the vendors display the pieces of meat on wooden or metal stands. The meats exposed under these conditions can be contaminated by physical, chemical, and microbial hazards (Food and Agriculture Organization of the United Nations – FAO, 2009). During frying, most vendors (56.7%) use bulk refined palm oil, 20% use sealed refined palm oil, 13.3% use bleached palm oil, and 10% use animal fats. Refined palm oil is a monounsaturated oil and is recommended for frying (Che Man & Tan, 1999; Pimpa et al., 2009). The bleaching of palm oil is traditional and can generate very toxic chemical contaminants such as glycidyl

fatty acid esters (GE) and 3-monochloropropanediol (3-MCPD) (Santiago et al., 2021). A proportion of 36.7% of vendors never change the frying oil but just add more when the volume of the frying oil decreases. 30% change the oil after a week, 16.7% after three days, and only 3.3% daily. It is known that frying oils should be renewed after 08 frying cycles (Choe & Min, 2007). Beyond that, the oils are often already quite degraded and contain oxidation compounds that are dangerous to human health (Stier, 2013; Urbancic et al., 2014). A proportion of 86.7% of the vendors claim to filter their frying oil, primarily using steel colanders (33.3%) and metallic sieves (40%). However, these filters only remove physical particles and do not improve the quality of the oil. If the oil is oxidised, the oxidation chemical compounds will remain in the oil even after filtration. Most of the vendors (73.3%) fried the meat at a normal temperature (165 – 180 °C).

Table 1. Frying conditions/practices and oil handling among street fried meat vendors

Variables		Frequency (%)
Display of meat	Glass display case	7 (23.3)
	Wooden/Metal display	23 (76.7)
Type of oil used	Sealed refined palm	6 (20.0)
	Bleached palm oil	4 (13.3)
	Animal fat	3 (10.0)
	Bulk oil	17 (56.7)
Daily frying time	2 - 4 hours	3 (10.0)
	4 - 6 hours	19 (63.3)
	6 - 8 hours	5 (16.7)
	8 - 10 hours	3 (10.0)
Replacement with fresh oil	Daily	1 (3.3)
	After two days	4 (13.3)
	After three days	5 (16.7)
	Weekly	9 (30.0)
	Never, just additions	11 (36.7)
Oil filtration	Yes	26 (86.7)
	No	4 (13.3)
Filter type	Steel colander	10 (33.3)
	Metallic sieve	12 (40.0)
	Frying spoon	2 (6.7)
	Drains top oil into another pot	6 (20.0)
Frying temperature	< 165 °C	6 (20.0)
	165 – 180 °C	22 (73.3)
	> 180 °C	2 (6.7)

Each indicator of food hygiene practices and conditions was scored as 1 for good practice/condition (in line with recommended food safety standards) and 0 for poor practice/condition (non-compliance). The individual scores for each respondent were summed to obtain their total practice/condition score. Vendors scoring ≥ 50% of the maximum possible score were classified as having overall food hygiene conditions and practices, while

those scoring below this threshold were classified as having poor food hygiene practices and conditions. Figure 2 indicates that the majority of the street meat vendors had poor food hygiene practices and conditions (66.8 %), whereas just a few (33.3 %) had good practices, indicating substantial gaps in food hygiene. Failure to comply with regulations exposes consumers to foodborne illnesses. For instance, Barro et al. (2006) demonstrated that silver coins and the hands of street food vendors harbour a large number of foodborne pathogens such as *Salmonella* and *Staphylococcus*. The results obtained are very close to those of Tampa et al. (2025), who conducted the same study in Western Cameroon and noted that most vendors did not adhere to basic food hygiene rules.

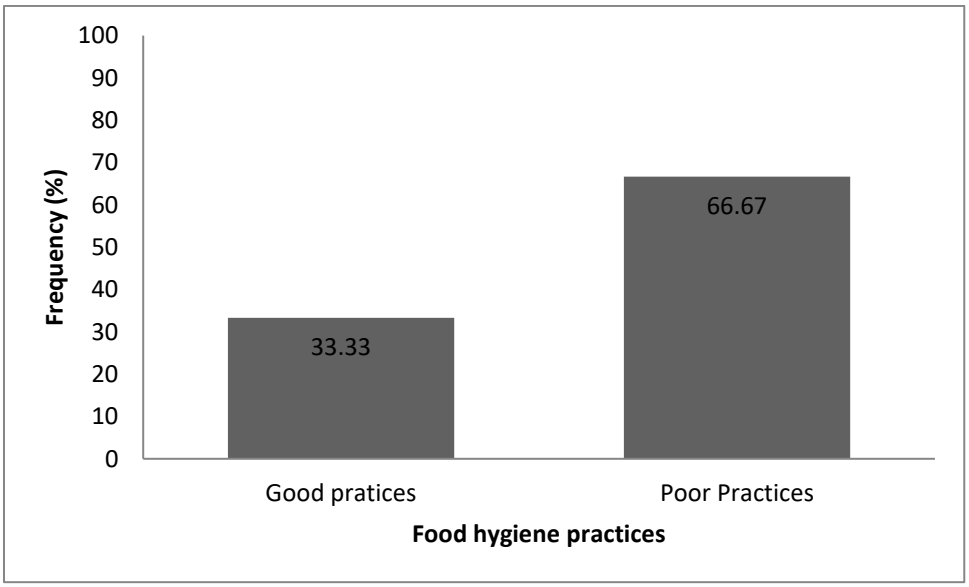
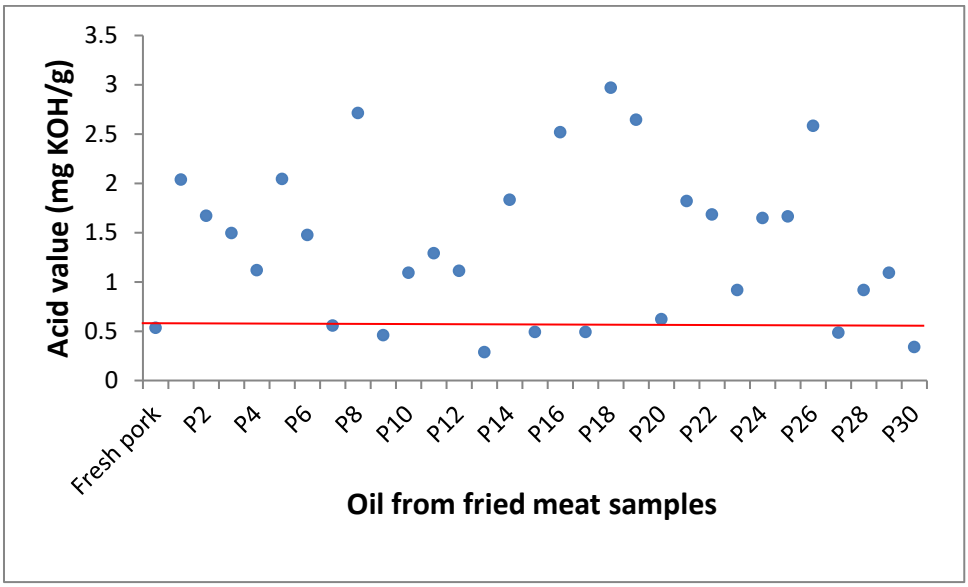


Figure 2. Overall food hygiene conditions and practices among street deep-fried meat vendors

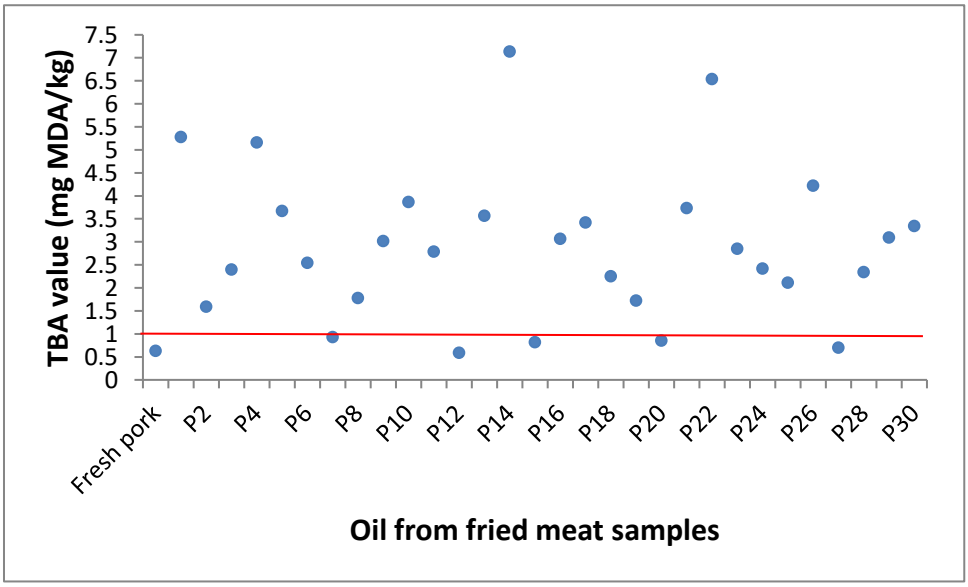
3.2.2 Quality analysis of the fat from the meat

Acid and thiobarbituric acid values were used to evaluate the quality of fat extracted from meats collected from different vendors. The standards indicating the acceptability thresholds allowed for the classification of the different samples (degraded fat and non-degraded fat). The results of figure 3 and 4 show that 77% of the analysed fats have an acid value higher than 0.6 mg KOH/g (standard according to the Codex Alimentarius, 1999). It is also noted that 83% of the fats have TBA values exceeding the standard threshold (1 mg/kg) (Mc Kenna et al., 2005) and are therefore unfit for consumption. TBA value measures the level of malondialdehyde, which is a secondary oxidation product of fats/oils whose toxicity has already been demonstrated in several previous studies (Uchida, 2003; Voulgaridou et al., 2011). The quality of the fat from the meat is strongly correlated with that of the frying oil

because it absorbs this oil during the cooking process. Teboukeu et al. (2025) indeed found high levels of secondary oxidation products in frying oils collected from vendors of fried pork. The fried meats collected from the vendors therefore mostly contain oxidation products that are potentially dangerous to consumers' health.

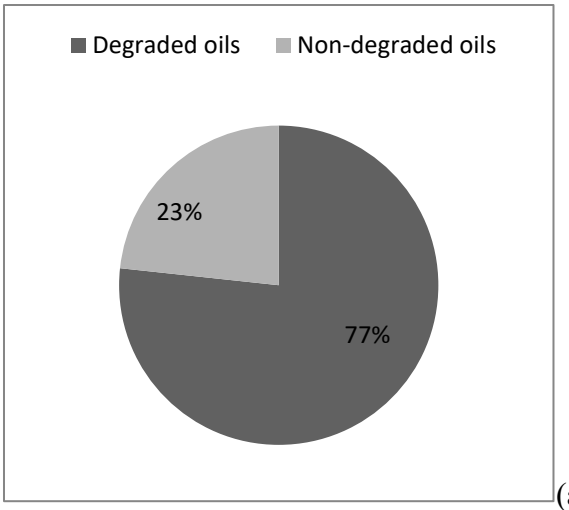


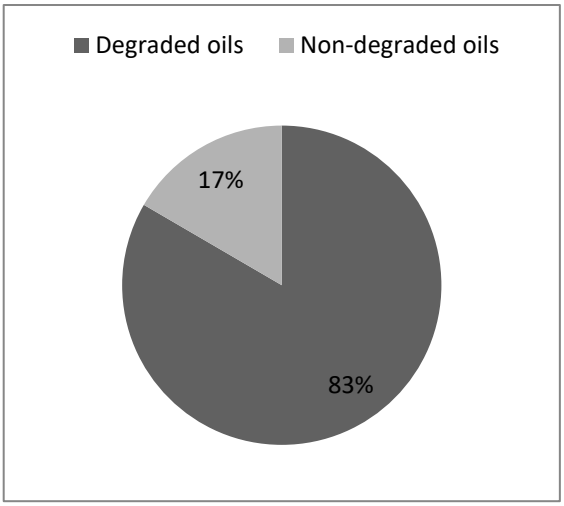
(a)



(b)

Figure 3. Acid value (a) and Thiobarbituric acid value (b) of the different sample oils compared to the standard limitation.



(a)


(b)

Figure 4. Distribution of oil from fried meat samples based on their state of degradation regarding the acid value (a) and thiobarbituric acid value (b)

3.2.3 Microbial analysis of ready-to-eat fried meat

The microbiological analysis of the various samples of ready-to-eat fried meat yielded the results presented in Table 2. Total mesophilic aerobic bacteria were found at an unacceptable level (>5.47 log CFU/g) in 63.34 % (19/30) of the meat samples. *Staphylococcus spp.* and coliforms were also found at an unacceptable level (>2 log CFU/g) in 43.33% (13/30) and 13.33% (04/30) of the samples, respectively. *Bacillus cereus* was detected but at an acceptable level in all samples, whereas *Salmonella spp.* was found at an unacceptable level in 6.67% (02/30) of the samples. The presence of pathogens in post-frying areas (equipment surfaces, serving utensils, handlers' hands) is one of the main routes of contamination of ready-to-eat meat (Zhu et al., 2005). For instance, Barro et al. (2006) demonstrated that silver coins and the hands of street food vendors harbour a large number of foodborne pathogens such as *Salmonella* and *Staphylococcus*. The contamination of these fried foods can also be due to the poor quality of the water used for washing and rinsing the serving utensils and to unacceptable concentrations of microorganisms present in the air of the sales location (Kirby et al., 2003 ; Salustiano et al., 2003).

Table 2. Microbial loads of different samples of ready-to-eat fried meat

Microorganisms	log CFU/g	**Standard Threshold*/Hazardous**	**Frequency (%)**	**Interpretation**
TMAB	3.02-5.32	<5.47 log CFU/g	11 (36.66)	Acceptable/Safe
	5.81-9.41	>5.47 log CFU/g	19 (63.34)	Unacceptable/Unsafe
Total coliforms	0.00-2.00	<2 log CFU/g	26 (86.67)	Acceptable/Safe
	2.11-3.01	>2 log CFU/g	04 (13.33)	Unacceptable/Unsafe
***Staphylococcus* spp**	0.00-2.00	<2 log CFU/g	17 (56.67)	Acceptable/Safe
	2.41-9.23	>2 log CFU/g	13 (43,33)	Unacceptable/Unsafe
Bacillus cereus	1.50×10^2 – 2.24×10^3	$<10^4$ CFU/g	30 (100)	Acceptable/Safe
		$>10^5$ CFU/g	00 (00)	Unacceptable/Unsafe
***Salmonella* spp.**	0.00-0.00	Absent	28 (93.33)	Acceptable/Safe
		Present	02 (6.67)	Unacceptable/Unsafe

TMAB : Total Mesophilic Aerobic Bacteria

3.3 Determination of critical control points (CCPs), establishment of critical limits, monitoring procedures and corrective actions

Once the hazard analysis was carried out at each stage of the fried meat production, the identification of critical points was made based on the decision tree of the production process and the results of the analyses of the different products during the process. Table 2 shows that control is essential to prevent, eliminate, or reduce a health hazard during three key stages (meat display, frying, and service) of the fried pork production process.

The presentation or display of pieces of boiled meat for customers to choose from is the first critical point. Most vendors use wooden or metal displays, which expose the food to physical, chemical, and microbiological hazards. To improve food safety during display, vendors should use glass or plastic cages that will limit the contact of meats with the external environment. These containers must also be thoroughly washed and disinfected before introducing the pieces of meat. Simple actions such as visual inspection and regular microbiological analyses of samples can ensure quality control at this stage.

During frying, the choice of frying oil quality and the number of frying cycles strongly impact the quality of the fried product. Most vendors do not comply with regulations, and the results of the analyses of the quality of fat for fried meats have shown the presence of oxidation compounds at very high concentrations in some samples. Control is therefore essential at this stage to limit chemical hazards. The vendors must use only monounsaturated oils for frying and completely change the frying oil after 08 cycles. The use of adsorbents to regenerate and reduce oxidation compounds in oils is also essential.

Service is also a critical control point. Service utensils such as kitchen dishes, when washed and rinsed with questionable quality water, can be a source of microbiological contamination of fried meats. The hands of the vendors who handle the meat and manage financial transactions at the same time also pose a microbiological hazard. It is therefore important that vendors clean the serving utensils with clean water and avoid handling food and money while serving food to consumers.

Table 3. Identification of critical control points (CCPs), establishment of critical limits, monitoring procedures and corrective actions

CCPs	Type of hazards	Critical limits	Monitoring procedure	Corrective actions
Meat display for attracting customers	Physical: stones, sand, dirt, dust, death insects	Complete absence of stones, sand, dirt, dust and death insects	Visual control of boiled meats to ensure they are free for stones, sand, dirt, dust and death insects	Use a plastic or glass display case daily that limits the meat's contact with the outside environment.
	Chemical: Polycyclic Aromatic Hydrocarbons (PAHs), Carbon Monoxide, and lead from car exhaust gases.	Complete absence of polycyclic Aromatic Hydrocarbons (PAHs), Carbon Monoxide, and lead.	To use a Portable Air Quality Sensor to capture real-time proxies for contamination.	Use a plastic or glass display case daily that limits the meat's contact with the outside environment.
	Biological: contamination by airbone microorganisms	Maximum Total Mesophilic Aerobic Bacteria (TMAB) count of 5.47 log Colony Forming Unit (CFU)/g	Regular microbiological analysis of meat sample	Use a plastic or glass display case daily that limits the meat's contact with the outside environment. Clean and disinfect the display before placing the pieces of meat.
Frying	Chemical: free fatty acids, aldehydes, acrylamide, 3-monochloropropane-1,2-diol and glycidol	Critical limits are defined by method performance (quantification) and regulatory safety thresholds.	Use of specialized laboratory analytical techniques combined with routine oil quality tracking.	Use monounsaturated oil. Change the frying oil after 06 frying cycles. Always monitor the frying temperature (165–180 °C). Filter the oil after 08 frying cycles with an adsorbent if you want to extend its usage duration.
Service	Biological: contamination by microorganisms from the hands of handlers or service tools (kitchen dishes, papers).	Screening for specific organisms using established guidelines based on standard thresholds (more details in Table 2)	Regular microbiological analysis of meat sample	Wash utensils and serving equipment in clean water. Avoid handling money and meat whilst serving.

3.4 Dietary exposure to malondialdehyde (MDA)

Malondialdehyde is a reactive aldehyde found in foods and is formed due to the decomposition of polyunsaturated fatty acid hydroperoxides (Papastergiadis et al., 2014). Figure 5 shows an estimated daily dietary exposure to malondialdehyde of the different meat samples. 9 out of 30 fried meat samples showed a daily intake of MDA exceeding the maximum threshold of 30 µg/kg body weight/day (European Food Safety Authority Scientific Committee, 2011). The other samples (21/30), including the fresh pork sample, showed a daily dietary exposure to malondialdehyde between 5.05 and 29.31 µg/kg body weight/day, indicating that these samples do not present any risk.

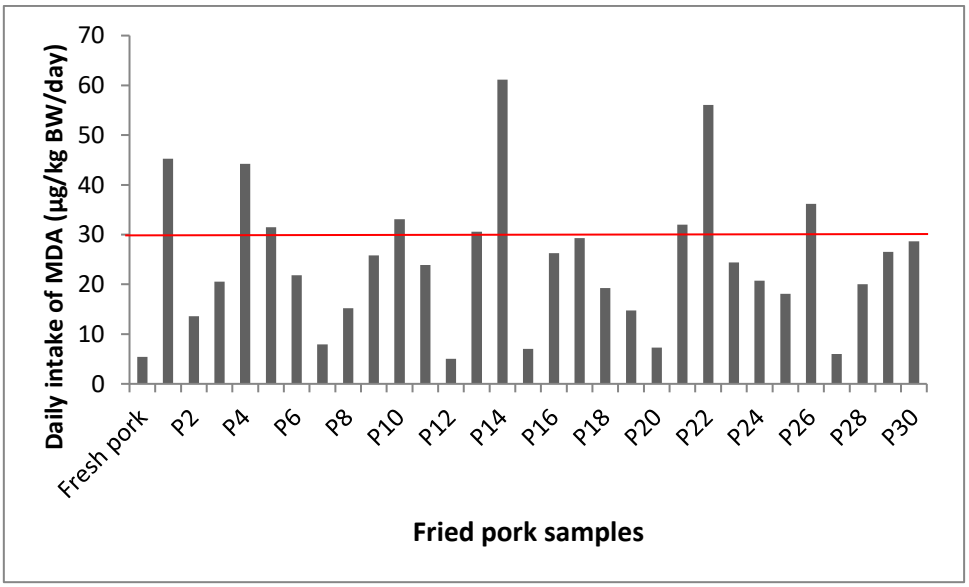


Figure 5. Estimated daily dietary exposure to malondialdehyde

An assessment of the overall level of exposure to malondialdehyde (Figure 6) indicates that 30% of the analysed samples pose dangers and expose the health of consumers. These samples contain large quantities of MDA and should not be consumed. Indeed, several studies have shown the potential toxicity of MDA in biological systems due to its high reactivity with proteins and DNA (Esterbauer et al., 1991; Uchida, 2003; Guillen & Goicoechea, 2008; Voulgaridou et al., 2011). More specifically, MDA can modify double-stranded DNA by forming bonds between the -NH2 groups of a guanosine base and the -NH2 group of the complementary cytosine base (Esterbauer et al., 1991). Papastergiadis et al. (2014) also found malondialdehyde in dry nuts, fried snacks, French fries, and cured minced meat products. However, only 3.8% of cured and minced raw meat presented a risk to human health if consumed.

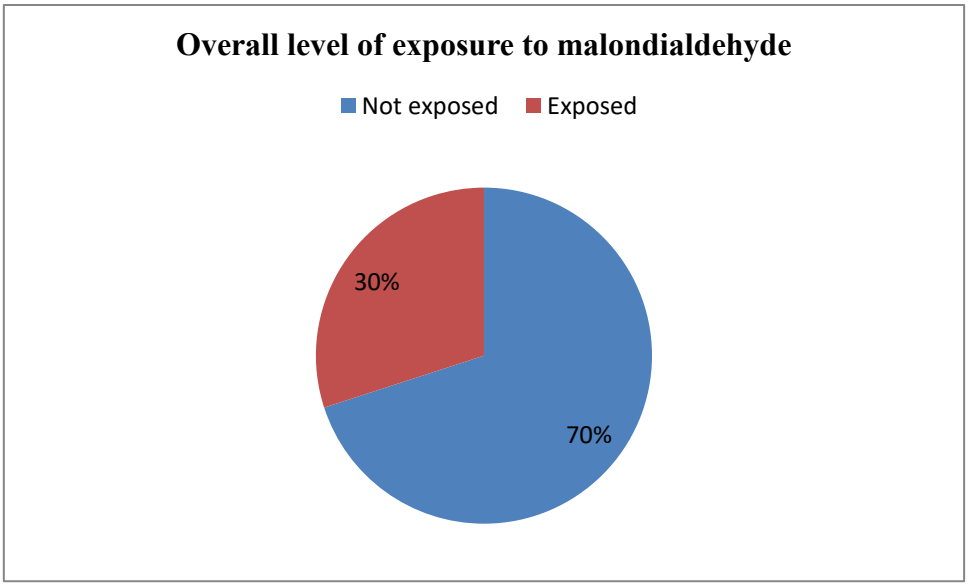


Figure 6. Overall level of exposure of consumers to malondialdehyde

4. Conclusion

This study demonstrates that deep-fried meat sold on the streets of Bamenda, North-West Cameroon, poses food safety risks due to degraded frying oils, high levels of oxidation products such as malondialdehyde, and poor hygiene. The identification of three critical control points (meat display, frying and service) provides a framework for targeted interventions. Implementing HACCP-based corrective actions is essential to reduce consumer exposure to chemical hazards, physical dangers and pathogens. Urgent measures such as raising awareness and training vendors, monitoring compliance with food hygiene regulations, and promoting safer frying practices are necessary to protect consumer health. This will contribute to maintaining fried meats from street vendors as a vital source of nourishment.

Authors' contributions

G.B.T: Writing original draft, Methodology, Investigation, Formal analysis, Conceptualization. **T.N.N :** Review and editing, Methodology, Conceptualization. **H.C.K.M :** Review and editing, Methodology. **B.P.N :** Investigation, Formal analysis. **P.N.N** : Review and editing, Validation, Supervision. All authors read and approved the final manuscript.

Funding

This research received no specific grant.

Data availability

The data that support the findings of this study are available on reasonable request from the corresponding author.

Competing interests

The authors declare no competing interests.

Ethics approval and consent to participate

Before collection data, the study was approved and the ethical clearance was obtained from the Faculty of Health Science of the University of Bamenda with Project Identification Number: 2024/0157H/UBa/IRB. The study was carried out in full conformity with universally recognized ethical standards for conducting human subject research. The street deep-fried meat vendors were visited, and the study objectives, procedure, and significance were clearly explained. The study was purely voluntary, and consent was sought from all the study participants before the beginning of the study. The study participants were clearly made aware of their right to decline to be part of the study or to withdraw at any stage of the study without any consequence. In cases where the study participant was illiterate, the consent form was clearly explained to them, and consent was given in the presence of an independent witness. Total confidentiality and anonymity were maintained throughout the entire study process, whereby no personal identifiers were used, and all data were kept for the sole purpose of conducting the study. The study was carried out in full conformity with the ethical principles of beneficence, non-maleficence, autonomy, and justice, with full adherence to the ethical standards of the Declaration of Helsinki and publication ethics as guided by the Committee on Publication Ethics (COPE).

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