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EDITED BY
Delia Grace,
University of Greenwich, United Kingdom

REVIEWED BY
Adriano Gomes Cruz,
Federal Institute of Rio de Janeiro (IFRJ), Brazil
Massimo Malacarne,
University of Parma, Italy

*CORRESPONDENCE
Gwladys S. Komagbe
✉ gkomagbe@yahoo.fr

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State of the art of breeding, milking, and milk processing for the production of curdled milk and *Wagashi Gassirè* in Benin: Practices favoring the contamination of its dairy products

Gwladys S. Komagbe[1,2]*, Alphonse Dossou[3,4,5], Baké Marie-Thérèse Seko Orou[6], Philippe Sessou[1], Paulin Azokpota[3], Issaka Youssao[7], Joseph Hounhouigan[3], Marie-Louise Scippo[4], Antoine Clinquart[5], Jacques Mahillon[2] and Souaïbou Farougou[1]

[1]Research Unit on Communicable Diseases, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Cotonou, Benin, [2]Laboratory of Food and Environmental Microbiology, Earth and Life Institute, UCLouvain, Louvain-la-Neuve, Belgium, [3]Laboratory of Food Sciences, Faculty of Agronomic Sciences, School of Nutrition and Food Sciences and Technology, University of Abomey-Calavi, Cotonou, Benin, [4]Laboratory of Food Analysis, Department of Food Sciences, Faculty of Veterinary Medicine, Fundamental and Applied Research for Animals and Health (FARAH), Veterinary Public Health, University of Liège, Liège, Belgium, [5]Laboratory of Food Technology, Faculty of Veterinary Medicine, Fundamental and Applied Research for Animals and Health (FARAH), University of Liège, Liège, Belgium, [6]Laboratory for Analysis of Social Dynamics and Development Studies (LADyD), Faculty of Agronomic Sciences, University of Abomey-Calavi, Cotonou, Benin, [7]Laboratory of Animal Biotechnology and Meat Technology, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, Cotonou, Benin

Introduction: This study aimed to identify the factors favoring the contamination of raw cow's milk, curdled milk, and *Wagashi Gassirè* cheese during their production and preservation in order to develop strategies to improve their quality.

Methods: A cross-sectional survey of 401 randomly selected stakeholders encompassing all levels of the dairy production chain in the Nikki and Dassa-Zoumé communes of Benin was conducted. The data obtained were analyzed using the SAS software for the calculation of frequencies and the R software for classifying the stakeholders based on the hygiene practices they adopted during the production and conservation of raw cow's milk, curdled milk, and *Wagashi Gassirè*.

Results and discussion: The study identified three types of dairy farmers based on how they medically treated their cattle and implemented hygiene practices, including farmers who (1) relied on themselves or received help from veterinarians trained in animal husbandry and milking to monitor the animals on their farms; (2) relied only on veterinarians; and (3) relied only on themselves. The majority of these dairy farmers felt that hygienic milking practices were very restrictive and difficult to implement. In addition, three groups of *Wagashi Gassirè* producers were identified: (1) producers trained in good hygiene practices who did not boil or sundry the cheese; (2) producers lacking the infrastructure to protect from weather exposure who used all parts of Calotropis procera for colored *Wagashi Gassirè* production; and (3) producers who did not often filter the milk and boiled the *Wagashi Gassirè* in bags before immersion in simple water or whey. The sanitary quality of milk and milk products is influenced by the diverse handling practices employed by producers. These practices must be considered according to the types of farmers and processors when suggesting improved intervention policies.

KEYWORDS

milk, cheese, hygiene, quality, Benin (West Africa)

1. Introduction

Like most West African countries, Benin's economy is based on agricultural production (Okry et al., 2017). The agricultural sector employs about 70 percent of the labor force, contributes nearly 23.3 percent to GDP, and provides about 75 percent of export earnings and 15 percent of government revenue (MPD, 2022). This sector is considered to have numerous potentialities that must be judiciously exploited to support national economic growth and thus contribute to effectively fight poverty. Most importantly, agriculture ensures Benin's food security (MAEP, 2017). In the agricultural production sector, livestock occupies a predominant place and contributes to the livelihood and food security of the population (Sounon et al., 2019). In 2012, the live-stock subsector, which plays an important role in the incomes of northern Beninese people, generated a revenue of USD 180.6 million (2.4% of GDP). In 2013, the national livestock population was estimated to be 4.6 million head, including 2.1 million cattle and 2.5 million small ruminants (MPD, 2022). However, the output of this subsector is plagued by the strong influences of various constraints, such as climatic, nutritional, sanitary, and genetic factors, that are at the root of major problems, including the low productivity of livestock (Soule et al., 2017). To overcome these obstacles and increase production, the government has implemented a series of projects including the Milk and Meat Sector Support Project (PAFILAV), which is part of the Growth Strategy for Poverty Reduction and the implementation of which has helped to increase production in the milk industry [Gouvernement du Bénin, 2022a; Groupes de la Banque Africaine de Développement (GBAD), 2022]. Indeed, the average number of lactating cows in Benin increased from about 495,000 in 2011 to more than 580,000 in 2015, and milk production increased from ∼102,000 tons in 2011 to 113,000 tons in 2015 (FAO, 2020). To boost milk production, the Government of Benin through its actions program for the period from 2021 to 2026, under pillar 2 relating to the pursuit of the structural transformation of the economy has planned to increase milk production through the development of the milk sector and the promotion of livestock farming enterprises (Gouvernement du Bénin, 2022b). With this program, the livestock sector is flourishing and interest in milk production has increased [Groupes de la Banque Africaine de Développement (GBAD), 2022]. Although milk production is increasing and makes a significant contribution to economic growth and to the food and nutritional security of the population, the marketed and sanitary quality of the milk is not always satisfactory and milk spoils rapidly under the influence of high environmental temperature in Benin (Sessou et al., 2013). To circumvent its quick and high adulteration, milk produced in Benin is often transformed into curdled milk and *Wagashi Gassirè* cheese using traditional processes. These products are important sources of protein and other essential nutrients and could help to eliminate protein deficiency in low-income populations (Dossou et al., 2016). They are part of the dairy products recognized worldwide as excellent sources of nutritional components (proteins, minerals, vitamins, lipids, and carbohydrates) and important part of the human diet (Verruck et al., 2019). Raw cow milk as well as curdled milk obtained *via* the spontaneous fermentation of raw cow milk are often consumed without any treatment by people in Benin in order to benefit from their nutritional elements (Farougou et al., 2012; Boko et al., 2016; Sessou et al., 2019). The traditional cheese *Wagashi Gassirè* is one of the most widespread dairy products in both rural regions and big cities and is widely appreciated by consumers in the Republic of Benin. It is also produced and consumed in many other West African countries, including Burkina Faso, Ghana, Nigeria, and Togo (Dossou et al., 2016; Zannou et al., 2018; Sessou et al., 2019). While these milk and traditional dairy products are enjoyed by consumers, they are also important in contributing to the nutritional health status of the population. In contrast to these potential benefits, it should also be recognized that these dairy products are perceived to be a major public health risk. Indeed, the practices generally used for the production and preservation of milk and milk derivatives do not always ensure their sanitary and nutritional quality. Contamination, particularly microbiological contamination, which leads to poor sanitary, nutritional, and marketable qualities, is commonly observed (Sessou et al., 2013). Since the demand for these pastoral dairy products, including *Wagashi Gassirè* and curdled milk, in local markets is increasing (Chabi Toko et al., 2015), it is essential to develop strategies to provide consumers with products of high sanitary and nutritional quality. Designing efficient strategies to improve the quality of these products requires knowledge of the different production and preservation practices adopted by all stakeholders in the milk production chain. Here, with this perspective, we analyzed the production and preservation practices that can cause the contamination of milk and milk products in two Beninese communes, Nikki and Dassa-Zoumé.

2. Materials and methods

2.1. Survey of dairy farmers, dairy producers, and consumers in the Beninese milk sector

A cross-sectional survey of dairy farmers, dairy producers, and consumers of the milk sector in the Beninese communes of Dassa-Zoumé and Nikki was conducted between May and July 2020 (Figure 1). The choice of these two areas was done since they are among the main cattle-breeding areas located in the center and north of Benin, respectively. A total of 401 participants, including cattle dairy farmers, dairy producers, traders, and consumers of curdled milk and *Wagashi Gassirè*, were surveyed (Table 1). The producers of fermented milk and cheese were predominantly women. Data were collected through guided interviews with each randomly selected participant using a structured questionnaire. This random approach was used as described in our previous paper (Dossou et al., 2022). The structured questionnaire was implemented using the Epicollect5 software. Field information concerning the hygienic practices implemented at all steps, i.e., milking, the production of cheese and curdled milk, preservation, and marketing, was obtained. Different questions specific to the production step were also asked. For instance, dairy farmers were asked questions regarding the hygiene measures implemented during milking and the therapeutic interventions used to treat sick cattle. The questionnaires included a list of various diseases in the local Fulani language; the questions and the answers were translated to French by trained veterinarians. The questions asked to dairy producers, traders, and consumers identified the existing production conditions and the product preservation methods being employed. During the study, the participation of respondents was voluntary, and participants provided informed consent before attempting the questionnaire (Dossou et al., 2022).

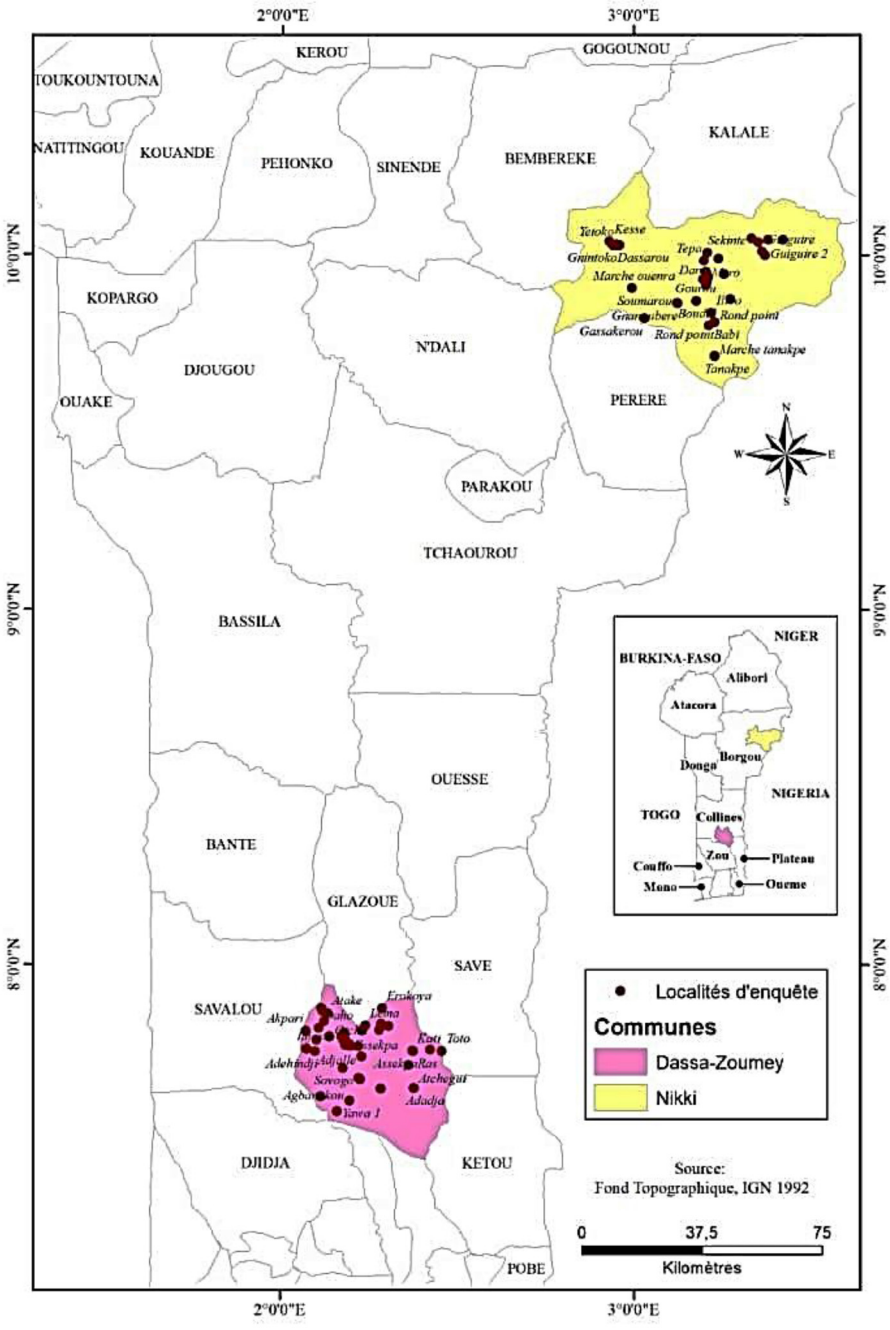

FIGURE 1
Map of the two study areas: Nikki in northern Benin and Dassa-Zoumé in central Benin.

2.2. Statistical analysis

The collected data were analyzed using the SAS (SAS, 2013) and R4.0.2 software. The PROC FREQ procedure of SAS was used to calculate frequencies, and the Chi² test to specify the significance of the common factor for the variables considered. For each relative frequency, a 95% confidence interval (CI) was calculated using the following formula:

$CI = 1.96\sqrt{([P(1-P)]/N)}$, where P is the relative frequency and N is the sample size.

The multiple correspondence analysis (MCA) function of R's FactoMineR library was used for multiple correspondence analysis (Husson et al., 2017; Cornillon et al., 2018) on a contingency table crossing the individuals in row and the variables in column. The variables considered are:

- For farmers: application of sanitary measures, implementation of hygienic measures during milking, hygienic measures observed during milking, hygiene training, availability of processing materials.

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TABLE 1 Distribution of respondents according to stakeholder category in each commune.

Stakeholder category	Commune		Total
	Dassa-Zoumé	Nikki	
Dairy farmers	54	30	84
Wagashi Gassirè producers	90	75	165
Curd producers	02	09	11
Traders of *Wagashi Gassirè* and curd	35	18	53
Consumers	56	32	88
Total	237	164	401

- For *Wagashi* producers: ethnicity, marital status, hygiene training, boiling and drying practices, immersion in whey, coloring of cheese, dye used, preservation method, filtering of milk, coagulant used.
- For traders: ethnicity, equipment, preservation methods and situation of sale point.
- For consumers: level of education, level of satisfaction and preservation methods. A hierarchical ascending classification (HAC) of the MCA components was then performed using the hierarchical clustering on principal components (HCPC) function. Stakeholder categories were then identified and characterized. The correspondence analysis (CA) function in R's FactoMineR library was used for factorial correspondence analysis (FCA) (Husson et al., 2017; Cornillon et al., 2018) on a contingency table crossing individuals in a row with variables in the column. The variables considered for the FCA are the level of education, ethnicity, and level of training on hygiene of the actors. The individuals are represented by the breeders, traders, *Wagashi* producers and consumers.

3. Results

3.1. Sociodemographic characteristics of the surveyed actors in the milk sector

The responses showed that milk farming is practiced exclusively by men (100%), the majority of whom are married and belong to the Fulani (87%) and Gando (13%) sociocultural groups in the two communes. Cattle rearing is therefore primarily carried out by the Fulani in the two communes surveyed. Overall, 93% of farmers were uneducated (91% in Dassa-Zoumé and 97% in Nikki). Women were the exclusive *Wagashi Gassirè* producers in both communes. In the Dassa-Zoumé commune, these women belonged to the Peulh (95%), Idaatcha (3%), and Fon (2%) sociocultural groups. In the Nikki commune, they be-longed to the Gando (77%) and Peulh (23%) sociocultural groups. Curd production was carried out mostly by women of the Peulh sociocultural group, with 100 and 89% in Dassa-Zoumé and Nikki, respectively. The survey revealed that the female producers were all uneducated, which could negatively influence the sanitary quality of their milk products due to a lack of knowledge on the safe handling of milk and dairy products. The analysis of the data showed that the *Wagashi Gassirè* traders belonged to the Baatonou, Dendi, Peulh, Fon, and Idaatcha tribes. In Nikki, 83% of traders were exclusively uneducated, whereas 43 and 31% of the traders in Dassa-Zoumé were uneducated and had a primary level education, respectively.

3.2. Dominant diseases in cattle identified by dairy farmers and their in-farm treatment strategies

As shown in Table 2, several diseases were found to be prevalent in the cattle farms surveyed. Arranged in descending order of importance, the dominant diseases were foot and mouth disease (FMD; 87%), pasteurellosis (62%), dermatophilosis (27%), trypanosomiasis (27%), lumpy skin disease (21%), and contagious bovine pleuropneumonia (18%). A comparison of the results obtained in the two communes (Table 2) revealed that pasteurellosis was significantly more prevalent ($p < 0.05$) in the commune of Nikki than in Dassa-Zoumé. These diseases were identified during the survey when a question was asked about the diseases often encountered on the participants' farms. The majority (64%) of dairy farmers reported that they diagnosed diseases themselves before administering treatment to the animals. When faced with these different diseases, the farmers adopted different treatment methods (Table 3). The majority (64%) of cattle dairy farmers treated their sick animals themselves, compared to 36% who relied solely on veterinarians. Some of the cattle dairy farmers who diagnosed and treated their animals themselves claimed to be self-taught, having learned either from their peers or from veterinarians, and 36% of cattle dairy farmers said that they had received training in treating animals. Two treatment types were identified in the survey: modern treatments and traditional treatments using bark and plant leaves. All the dairy farmers surveyed used modern treatments and obtained drugs from veterinary clinics by describing the symptoms of their animals to the veterinarians or pharmacists. Of these, 68% combined modern and traditional treatments. An inventory of the antibiotics used to treat animals based on the medicine labels found in the dairy farmers' homes showed that the most commonly used antibiotics were penicillin, streptomycin, oxytetracycline, tylosin, and sulphonamides. These antibiotics were also purchased from veterinary pharmacies, as the quality of products on the black market is doubtful. A total of 59% of the respondents estimated the weight of the animal and the dosage without referring to the manufacturer's instructions, and the rest (41%) determined the dosage according to the manufacturer's instructions by estimating the weight of the animal. In addition, all respondents did not respect the post-treatment waiting period for milking. The majority (98%) of the surveyed dairy farmers said that milk from cows treated with antibiotics was used either for direct human consumption or for processing into *Wagashi Gassirè* or curdled milk, in contrast to the remaining 2% who rejected this type of milk (Table 4). Compared to Nikki, the Dassa-Zoumé commune had a significantly higher proportion of dairy farmers who treated animals without veterinary help and used milk collected during the treatment period. Consequently, the probability of having dairy products contaminated with drug residues is higher in Dassa-Zoumé than in Nikki.

TABLE 2 Dominant diseases identified in farm animals and disease diagnosis in the communes of Dassa-Zoumé and Nikki.

Variable	Both communes			Dassa-Zoumé			Nikki			Chi^2 test
	N	%	CI	*N*	%	CI	*N*	%	CI	
Dairy cattle diseases (local dialect)										
Foot and mouth disease (*Tchabou*)	73	86a	8	46	91a	8	27	78	16	NS
Pasteurellosis (*Hinrin*)	73	62b	11	46	52	14	27	78	16	*
Nodular dermatosis (*Borla*)	73	21c	9	46	26	13	27	11	12	NS
Dermatophilosis (*Goungnan*)	73	27c	10	46	22	12	27	37	18	NS
Brucellosis (*Konedjé*)	73	7d	6	46	9	8	27	4	7	NS
PPCB (*Otel*)	73	18c	9	46	24	12	27	7	10	NS
Trypanosomiasis (*Samorin*)	73	27c	10	46	30	13	27	22	16	NS
Calf plague (*Tchibel*)	73	1d	3	46	2	4	27	0	0	NS
Other	73	7d	6	46	7	7	27	7	10	NS
Diagnosed and treated by who										
Dairy farmer	84	64b	10	54	72	12	30	50	18	*
Veterinarian	84	36a	8	54	28	10	30	50	15	NS

*$p < 0.01$; *N*, number; NS, not significant; %, percent of respondents; CI, confidence interval; a, b, c, d—values from the same column followed by the same letter were not significantly different at the 5% level. Chi^2- tests were performed for variables from both communes in the same line.

TABLE 3 Mode and type of treatment of listed livestock diseases and sources of drugs.

Variable	Both Communes			Dassa-Zoumé			Nikki			Chi^2 test
	N	%	CI	*N*	%	CI	*N*	%	CI	
Basis for treatment choice by dairy farmers who diagnose and treat diseases themselves										
Self-taught	54	19b	10	39	17	12	15	7	13	NS
Professionally trained	54	36ab	13	39	28	14	15	43	25	NS
Mixed (self-taught and professionally trained)	54	45a	13	39	55	15	15	50	25	NS
Type of treatment used										
Modern only	54	32b	12	39	31	15	15	33	24	NS
Modern and traditional	54	68a	12	39	69	15	15	67	24	NS
Supply sources of drugs										
Veterinary office	54	87a	10	39	85	11	15	93	13	NS
Informal source	54	13b	9	39	15	11	15	7	13	NS
Non-compliance with waiting period	54	100	0	39	100	0	15	100	0	NS
Choice of timeframe										
Self-taught	54	74a	12	39	72	14	15	80	20	NS
Veterinarian's instructions	54	17b	10	39	15	11	15	20	20	NS
Mixed (self-taught and veterinarian's instructions)	54	9b	8	39	13	11	15	0	0	NS

N, number; NS, not significant; %, percent of respondents; CI, confidence interval; a, b—values followed by the same letter were not significantly different at the 5% level. Chi^2 tests were performed for variables from both communes in the same line.

3.3. Hygiene measures implemented by dairy farmers during milking

In Benin, all farmers use a hand milking procedure. The hygiene measures implemented by dairy farmers during milking are shown in Table 5. The analysis of the data on milking equipment revealed that most of the respondents (96%) used milking equipment only for milking. Milking equipment was either stored in rooms, hung on trees, or placed on open racks, exposing it to environmental microorganisms. Plastic equipment was used more frequently ($p < 0.001$) in Dassa-Zoumé than in Nikki. In contrast, calabashes were used more ($p < 0.001$) frequently in Nikki than in Dassa-Zoumé.

TABLE 4 Use of milk from cows treated with antibiotics without respecting the withdrawal period.

Variable	Both communes			Dassa-Zoumé			Nikki			Chi^2 test
	N	%	CI	*N*	%	CI	*N*	%	CI	
Consumption/transformation	42	98a	4	31	97	6	11	100	0	NS
Rejection	42	2b	4	31	3	6	11	0	0	NS

N, number; NS, not significant; %, percent of respondents; CI, confidence interval; a, b—values followed by the same letter were not significantly different at the 5% level, while means followed by different letters were significantly different at the 5% level. Chi^2 tests were performed for variables from both communes in the same line.

TABLE 5 Types of equipment used for milking and curd production.

Variable	Both Communes			Dassa-Zoumé			Nikki			Chi^2 test
	N	%	CI	*N*	%	CI	*N*	%	CI	
Milking material										
Plastic	73	67a	11	46	96	6	27	19	15	***
Calabash	73	29b	10	46	2	4	27	74	17	***
Plastic and calabash	73	3c	4	46	0	0	27	7	10	NS
Stainless steel	73	1c	2	46	2	4	27	0	0	NS

***$p < 0.001$; *N*, number; NS, not significant; %, percent of respondents; CI, confidence interval; a, b, c—values followed by the same letter were not significantly different at the 5% level. Chi^2 tests were performed for variables from both communes in the same line.

The majority (98–100%) of the dairy farmers washed the milking utensils after milking, whereas only a minority (2–5%) washed them just before milking. Only 38% of the dairy farmers surveyed claimed to wash their hands before milking. Approximately 11% of the dairy farmers claimed to be trained in good milking hygiene practices, but only 5% implemented these practices. The majority who did not implement them felt that these practices were very restrictive and difficult to implement.

3.4. *Wagashi Gassirè* production practices

The unit operations of the *Wagashi Gassirè* production process that could influence its sanitary quality were investigated. Only 28 and 8% of the cheese producers in Dassa-Zoumé and Nikki, respectively, had cheese-making rooms that were laid out for improved protection from weather (Table 4). Consequently, although the *Wagashi Gassirè* cheese produced in both communes was exposed to external pollutants, including microbiological and physical hazards, it was exposed to a significantly greater extent in the Nikki commune ($p < 0.01$). While 72% of the cheese producers in Dassa-Zoumé filtered the milk used for cheese production, only 59% implemented this step in the Nikki commune. *Calotropis procera*, which is used for milk coagulation, was procured from markets (or known clients) in 72% of cases in Dassa-Zoumé. The majority of Nikki cheese producers obtained *Calotropis procera* directly from the fields (99%). After molding, *Wagashi Gassirè* is stored immersed in either water or whey, and 92 and 50% of the producers in the Dassa-Zoumé and Nikki communes, respectively, followed the immersion in whey method of storing. In addition, 50% of the female producers immersed the cheese in plain water after molding. Generally, the cheese is colored using different techniques and raw materials. In Dassa-Zoumé, the coloring of *Wagashi Gassirè* cheese was mostly performed (69.33%) using sorghum panicles procured from markets, while in Nikki, sorghum ears were used for coloring. Touhi bark or teak leaves (*Tectona grandis*) were also used for coloring by many female producers. For coloring, sorghum panicles added to potash (followed by 67% of producers in Dassa-Zoumé) or to salt/bicarbonate (followed by a smaller proportion of producers) were used in either hot (cooking) or cold (trituration of the dye in water) methods. Importantly, very few cheese producers (9% in Dassa-Zoumé and 9% in Nikki) were trained in hygienic *Wagashi Gassirè* production practices.

3.5. Conditions of curd production

The milk used for curd production was mostly filtered in both communes. Curd producers in Dassa-Zoumé exclusively used plastic equipment for fermentation (Table 5). In contrast, in the Nikki commune, stainless steel or enamel equipment was also used in addition to plastic. Moreover, the fermentation equipment was not solely reserved for curd making; this multipurposing could lead to the cross-contamination of the dairy products.

3.6. Market conditions for selling *Wagashi Gassirè*

The results showed that *Wagashi Gassirè* was sold by traders untrained in good hygiene practices. They also lacked the infrastructure to protect the cheese from environmental contamination. As a result, it was exposed to microbiological, physical, and chemical hazards. This study considered consumers with varying levels of education and of both sexes. In both Dassa-Zoumé and Nikki, most respondents were educated. According to the educated respondents, the hygiene conditions at the time of sale of *Wagashi Gassirè* were less than satisfactory (Table 6). In contrast, the uneducated consumers responded that hygiene conditions at the time of sale of *Wagashi Gassirè* were satisfactory. After buying, the consumers in the commune of Nikki made significant use ($p <$

TABLE 6 Milking hygiene measures implemented on farms.

Variable	Both communes			Dassa-Zoumé			Nikki			Chi^2 test
	N	%	CI	*N*	%	CI	*N*	%	CI	
Training in milking hygiene	84	11	7	54	13	9	30	7	9	NS
Implementation of hygiene practices	84	5	5	54	29	10	30	100	0	*
Hand washing before milking	73	38	11	46	37	14	27	41	19	NS
Other use of milking materials	84	4	4	54	4	5	30	3	6	NS
Washing of utensils after use	73	100	0	46	100	0	27	100	0	NS
Washing of utensils just before use	73	7	6	46	2	4	27	15	13	*

*$p < 0.05$; *N*, number; NS, not significant; %, percent of respondents; CI, confidence interval. Chi^2 tests were performed for variables from both communes in the same line.

TABLE 7 Consumer assessment of hygiene conditions at the time of sale and preservation methods.

Variable	Both communes			Dassa-Zoumé			Nikki			Chi^2 test
	N	%	CI	*N*	%	CI	*N*	%	CI	
Hygiene conditions during the sale										
Satisfactory	88	42b	10	56	45	13	32	38	17	NS
Unsatisfactory	88	58a	10	56	55	13	32	62	17	
Preservation method										
Cooking	86	48a	11	54	59	13	32	28	16	**
Refrigeration	86	7d	5	54	11	8	32	0	0	NS
Frying	86	30bc	10	54	37	13	32	19	14	NS
Smoking	86	41ab	10	54	43	13	32	38	17	NS
Cooking in salted water	86	21c	9	54	19	10	32	25	15	NS
Sun drying	86	33bc	10	54	11	8	32	69	16	***

**$p < 0.01$; ***$p < 0.001$; *N*, number; NS, not significant; %, percent of respondents; CI, confidence interval; a, b, c, d—values followed by the same letter were not significantly different at the 5% level. Chi^2 tests were performed for variables from both communes in the same line.

0.001) of sun drying to pre-serve *Wagashi Gassirè*, compared to daily heating in water, which was utilized by consumers in Dassa-Zoumé. Other methods used by consumers to preserve cheese included refrigeration, frying, and hot smoking. The level of microbiological contamination in *Wagashi Gassirè* would therefore depend on the preservation method used, especially because sun drying exposes the cheese to more microbes (Table 7).

3.7. Classification of actors according to hygiene practices

3.7.1. Classification of dairy cattle farmers

This study characterized the dairy cattle farmers and classified them into different groups. The first three axes were used to interpret the MCA results. The total inertia of the three axes was 57.97%, with 27.24% on the first axis, 21.39% on the second axis, and 9.34% on the third axis (Figure 2). Group 1 dairy cattle farmers treated their animals themselves or with help from veterinarians. These farmers also practiced milking hygiene measures. For example, they washed and dried the collection utensils and washed their hands before milking. Group 2 consisted of dairy cattle farmers who used veterinarians to monitor their animals and who had received training in animal husbandry and milking, which they implemented on their farms. Group 3 consisted of dairy farmers who treated their animals themselves, without help from veterinarians. These individuals had not received any training in milking hygiene. Training in good hygiene practices should be implemented for all farmers, but especially for the latter group, and a rigorous follow-up of the application of these good practices should be carried out to improve the sanitary quality of the milk produced in these breeding areas.

3.7.2. Classification of female *Wagashi Gassirè* producers

This study identified three groups of female *Wagashi Gassirè* producers. The first three axes were used to interpret the MCA results. The total inertia of the three axes was 36.98% with 21.98%, 10.38%, and 4.61% on the first, second, and third axes, respectively (Figure 2). Axis 1 contrasts the female producers in Groups 1 and 3 with those in Group 2. Axis 2 compares female producers in Group 3 to those in Groups 1 and 2 (Figure 3). Group 1 consisted of women who were trained in good production hygiene practices. They did not scald or sun dry their cheese. Most also did not immerse the cheese in whey and did not color it. In addition, they put the

cheese in salted water but did not smoke it. Group 2 consisted of single female producers who did not have infrastructure, such as properly laid out cheese-making rooms, to protect the cheese from weather exposure. They used filtered milk to make *Wagashi Gassirè* by coagulating the milk with the leaves, stems, and sap of *Calotropis procera*. They mainly produced red cheese. The cheese was colored with residues of sorghum (panicles and ears) and teak (Touhi bark and leaf). These producers were of the Gando and Peuhl ethnic groups, and they also sun-dried the cheese. Group 3 consisted of female producers from the Idaatcha ethnic group. They often skipped the milk filtration step and sometimes used papaya leaves to coagulate milk. They used vegetables and plastic strainers for draining. They preserved the *Wagashi Gassirè* by boiling in bags and storing the cheeses immersed in plain water and whey. They also smoked the *Wagashi Gassirè* for better preservation. Therefore, it is important to assess the sanitary quality of products according to these groups and to initiate training on good hygiene practices for these groups according to their individual needs.

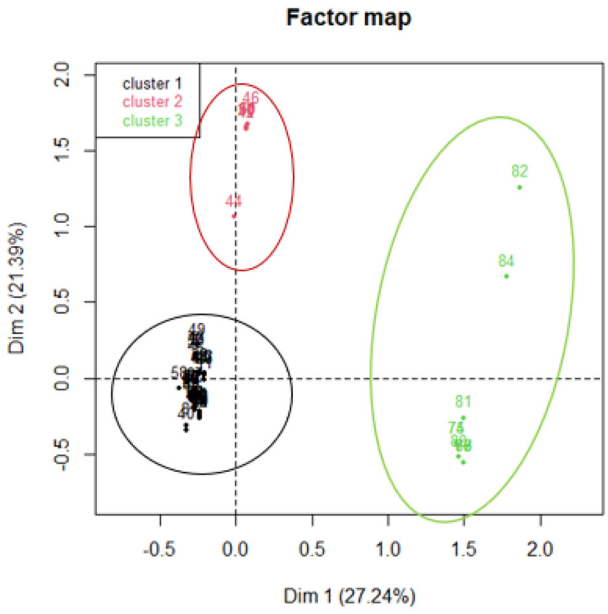

FIGURE 2
Classification of cattle dairy farmers in Dassa-Zoumé and Nikki.

3.7.3. Classification of female *Wagashi Gassirè* traders

This study identified two groups of female *Wagashi Gassirè* traders. The first two axes were used to interpret the MCA results. The total inertia of the three axes was 22.79%, with 12.72% on the first axis and 10.07% on the second axis (Figure 4). The female traders were opposed on axis 2. The first group comprised female traders from the Baatonou, Fon, Mahi, and Peuhl tribes who worked either on the edge of the streets, at crossroads, or as street vendors. They preserved cheese by drying it in the sun and cooking it daily in salted water. The products sold by these groups could therefore be contaminated by environmental microorganisms and chemical contaminants from vehicles on the streets and intersections. The second group consisted of vendors from the Idaatcha, Yoruba Dendi, and Mina tribes. They preserved *Wagashi Gassirè* by boiling it either enclosed in or without plastic bags. Contamination from the plastics used for cooking is possible under these conditions, affecting the sanitary quality of these products at the chemical level and weakly at the microbiological level.

3.7.4. Classification of consumers

The first three axes were used to interpret the MCA results. The total inertia of the three axes was 44.10 with 17.52%, 15.12, and 11.45% on the first, second, and third axes, respectively (Figure 5). Axis 2 contrasted the female consumers in Group 3 with those in Groups 1 and 2 (Figure 5). Group 1 consisted of

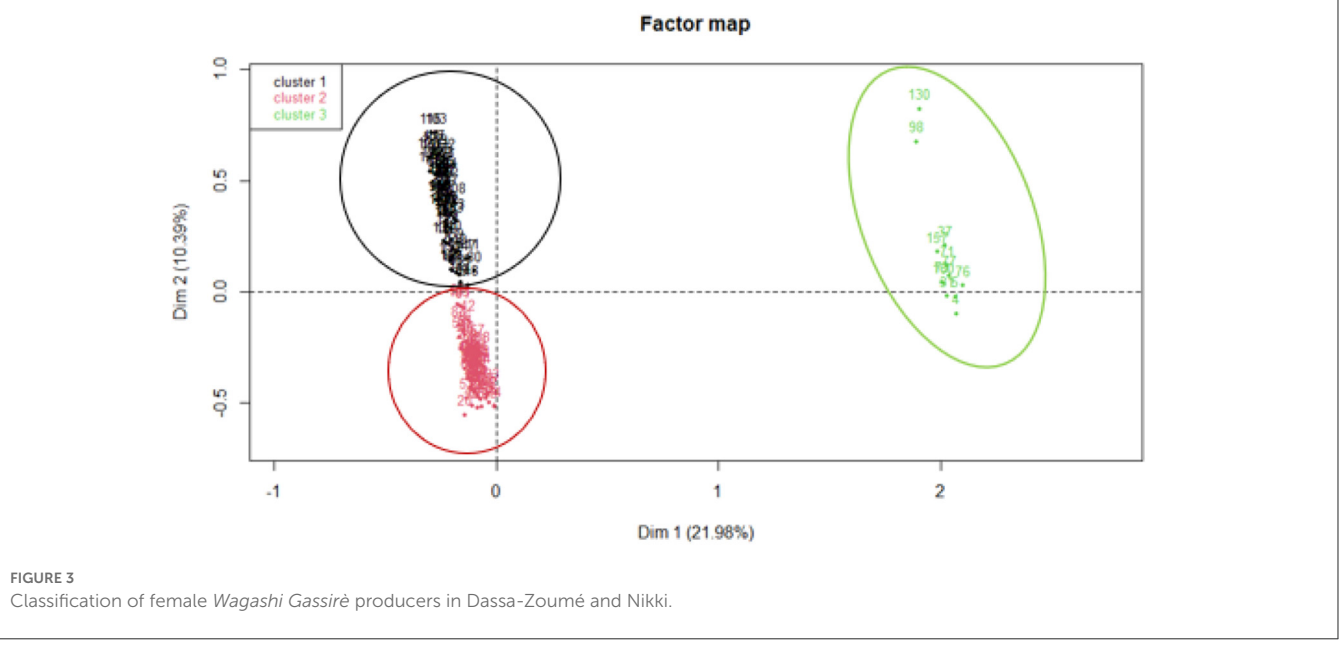

FIGURE 3
Classification of female *Wagashi Gassirè* producers in Dassa-Zoumé and Nikki.

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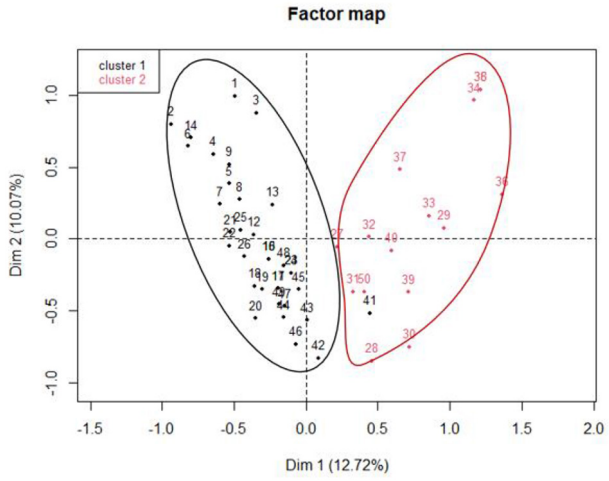

FIGURE 4
Classification of *Wagashi Gassirè* traders in Dassa-Zoumé and Nikki.

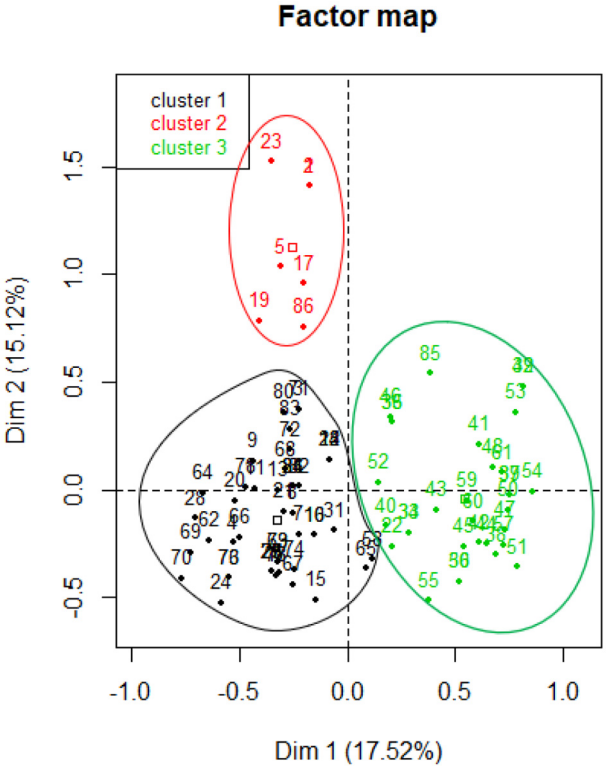

FIGURE 5
Classification of *Wagashi Gassirè* consumers from Dassa-Zoumé and Nikki.

secondary-school-level educated consumers who practiced frying and sun-drying *Wagashi Gassirè*. Group 2 consisted of university-level educated consumers who cooked and refrigerated *Wagashi Gassirè* for preservation and were not satisfied with the hygienic conditions under which the *Wagashi Gassirè* was sold. Group 3 consisted of uneducated consumers who smoked and cooked the cheese in salted water for storage; they were satisfied with the hygiene conditions of the market. Therefore, the appreciation of the level of hygiene depends on the education level of the consumers; however, abnormally, the uneducated consumers fortunately seem to adopt practices for treating the cheese that support the destruction of microbiological contaminants.

3.8. Presentation of stakeholders according to level of education, ethnicity, and hygiene training

The analysis of the dairy stakeholders according to their sociocultural group as well as their level of education and training on hygiene practices during the milking, production, and preservation of curdled milk and *Wagashi Gassirè* revealed that the *Wagashi Gassirè* trade was practiced by the Dendi and Baatonou in Nikki and the Fon and Idaatcha in Dassa-Zoumé. Milk farming was practiced by mostly uneducated Fulani farmers, some of whom had received training in hygiene, while the female producers of *Wagashi Gassirè* were mostly uneducated and from the Fulani and Gando tribes.

4. Discussion

The husbandry and hygiene practices adopted in the production, processing, and distribution of milk not only affect the quality of the raw milk and its byproducts, but also directly affect human and animal health. Moreover, they also have economic implications (Singh and Ramachandran, 2020). Here, the various stakeholders in the dairy chain were characterized and factors that may affect the sanitary quality of milk and its derivatives in Benin were identified. This study revealed that cattle rearing is practiced mostly by uneducated men of the Fulani group in the two communes considered. In agreement with these results, Dahouda et al. (2019) reported that the majority (62.73%) of cattle dairy farmers in Nikki were of the Fulani ethnic group. The lack of education among most farmers acts as a handicap in the implementation of good husbandry and hygiene in milking practices. According to Gökdai et al. (2020), the education level of stakeholders influences the observance of good hygiene practices on the farms; uneducated farmers fail to master good hygiene and husbandry practices and lack an understanding of the risks associated with bad practices. Several diseases, mainly foot and mouth disease, pasteurellosis, dermatophilosis, trypanosomiasis, lumpy skin disease, contagious bovine pleuropneumonia, brucellosis, and calf plague, were found to be prevalent in the surveyed cattle farms, corroborating the findings of Kpodékon et al. (2015), who showed that foot and mouth disease is the dominant viral disease in cattle farms in northern Benin. Sow (2014) also observed that (arranged in decreasing order of importance) foot and mouth disease, pasteurellosis, trypanosomiasis, botulism, lumpy skin disease, mastitis, and symptomatic anthrax were the dominant diseases encountered in dairy cattle farms in the regions of Thiès and Diourbel in Senegal. These diseases cause significant economic losses in terms of milk production and skin condition in the affected animals. Apart from these economic consequences, some of these diseases encountered in animals, such as brucellosis, can affect the quality of milk and meat and consequently the health of consumers. They are diagnosed and

treated by the farmers themselves, mostly with antibiotics purchased from pharmacies or veterinary clinics. Consistently, in another study, 76.7% of farmers used antibiotics without veterinary assistance for the treatment of diseases encountered on cattle farms in northern Benin (Mensah et al., 2019). Similarly, Dognon et al. (2018) observed that only 49% of farmers used the veterinary services in northern Benin for the treatment of their animals. While 59% of farmers obtained veterinary drugs from local markets, 41% procured them from veterinary pharmacies. Here, the antibiotics commonly used to treat animals were penicillin, streptomycin, oxytetracycline, tylosin, and sulphonamides. These results agree with the reports of Dognon et al. (2018) and Mensah et al. (2019), who observed that tetracyclines, penicillin, sulphonamides (47%), and macrolides (17%) were the antibiotic families most used by livestock keepers in northern Benin for treating sick cattle. Most respondents in this study did not follow the manufacturer's instructions when estimating weight and the dosage of the medicine. This proves the existence of the rampant misuse of antibiotics on cattle farms in the surveyed communes. The guidelines for the post-treatment waiting period were disregarded by all respondents, and the milk from antibiotic-treated cows was used either for direct human consumption or for processing into *Wagashi Gassirè* or curdled milk. These practices suggest an increased likelihood of the contamination of dairy products with antibiotic residues and antibiotic-resistant bacteria, which can adversely affect consumer health (Dognon, 2018). The practice of the unhindered consumption or processing of raw milk contaminated in this manner by concerned stakeholders could possibly be explained by a lack of understanding of the associated health risks by the high number of uneducated respondents in this survey. Plastics and calabashes are the most commonly used materials for milking equipment. The use of calabashes favors the formation of microbial biofilms that can participate in the rapid fermentation of raw milk. Unlike plastic, which can be properly cleaned when soap and drinking water are available, calabashes cannot be disinfected easily (Gagara et al., 2019). According to Kebede et al. (2007), the use of different types of containers for milk collection significantly influences the diversity of the flora present in curdled milk and the characteristics of the resulting milk product. Only a minority of the responders complied with many hygiene measures; in particular, hand washing procedures were not followed during the production and preservation of raw milk, curdled milk, and *Wagashi Gassirè*. Group 3, which consisted of dairy cattle farmers who treated their animals themselves without help from veterinarians and had no training in milking hygiene, was the most targeted as not following good hygiene practices. The absence of good hygiene practices reported by majority of respondents and the non-washing of hands, which are reservoirs of microorganisms including *Staphylococcus* in wound infections and fecal coliforms, highlighted that the probability of the contamination of milk and dairy products by pathogenic germs is very high; this was confirmed in the works of Farougou et al. (2012), Boko et al. (2016), Gouissi et al. (2017), Sessou et al. (2019), and Djobo et al. (2021). Indeed, the work of Djobo et al. (2021) showed that raw cow milk from Benin was of unsatisfactory quality, with 1.8×10^8 CFU/mL for total aerobic mesophilic flora (TMC), 4.0×10^7 CFU/mL for fecal coliforms (FC), 3.5×10^7 CFU/mL for *Escherichia coli*, 2.8×10^7 CFU/mL for total coliforms (TC), 2.1×10^7 CFU/mL for fecal Streptococci (FS), 1.6×10^7 CFU/mL for yeasts and molds (YM), 1.7×10^7 CFU/mL for sulfur-reducing anaerobic bacteria (SRA), and 1.2×10^7 CFU/mL for *Staphylococcus* spp. The same observations were recorded by Farougou et al. (2012), where raw cow milk samples collected from Dassa-Zoumé were determined to be unsatisfactory regarding the total mesophilic aerobic flora (1.1×10^8 CFU/ mL), fecal coliforms (9.2×10^2 CFU/mL1), *Escherichia coli* (0.4×10^1 CFU/mL), and *Staphylococcus aureus* (4.0×10^1 CFU/mL). Boko et al. (2016) revealed that the average fecal coliforms in curdled milk made from raw cow milk varied from $11.313 \pm 13 \times 10^3$ CFU/mL at 30°C to $0.983 \pm 1.228 \times 10^3$ CFU/mL, while the average *Escherichia coli* count was 0.34 ± 0.89 CFU/mL. Gouissi et al. (2017) and Sessou et al. (2019) showed that *Wagashi* cheese was of poor microbial quality when some pathogens were present. The presence of *Escherichia coli* used as reliable indicator of fecal contamination indicates possible presence of enteropathogenic and/or toxigenic microorganisms which constitute a public health hazard. The low proportion of stakeholders who implement hygiene measures indicates a lack of awareness regarding the risks associated with non-compliance. Therefore, increasing stakeholders' awareness of good hygiene practices in milking and milk handling is necessary to obtain safe, high-quality dairy products. The results obtained regarding preservation methods corroborate the findings of Sessou et al. (2013), who inventoried the methods studied here and found limitations in *Wagashi Gassirè* production and preservation methods, reflected by their low sanitary quality. The existence of stakeholder subcategories indicates diversity in the employed husbandry and hygiene practices, and consequently diversity in the sanitary and nutritional quality of the target dairy products. In view of these findings, the products targeted may present potential risks for public health during their consumption, given their contamination with the above-mentioned microorganisms and findings reported in other studies (Michael and Mullan, 2019; Idland et al., 2022). Indeed, several studies have identified milkborne pathogens including Shiga-toxin producing *Escherichia coli* (STEC), *Campylobacter jejuni*, *Listeria monocytogenes*, *Salmonella* spp. and *Yersinia enterocolitica* in dairy products. The presence of these pathogenic bacteria in milk emerged as major public health concerns, especially for those individuals who still drink raw milk or eat these uncooked dairy products. These bacterial pathogens are a substantial source of health loss globally (Ahmadi, 2019; Idland et al., 2022). To improve the safety quality and shelf-life of dairy products, factors that contribute to microbiological contamination must be considered at the level of every stakeholder cluster in the dairy chain. The critical points found in this study will be used to improve hygiene quality of dairy products in Benin. Although this study has provided valuable information on the milk sector in Benin for the improvement of dairy products, there are some limitations to our study due to the selection approach of our participants; there was an uneven distribution of participants from different area. Future studies should use more rigorous sampling methods, for example in a nationally representative household survey, specifying balanced and adequate representation of important demographic groups. On the other hand, the reluctance of farmers to report truthful status could bias the information obtained.

5. Conclusions

This study assessed the production and storage practices of raw cow's milk, curdled milk, and *Wagashi Gassirè* in two Beninese communes. Several factors were found to affect the sanitary quality

of dairy products in these regions. These included the misuse of antibiotics on farms, the non-implementation of good hygiene practices by stakeholders, the sale of products in the open air (as a source of contamination), and the non-availability of coagulants, especially in the Dassa-Zoumé area. This study also confirmed the prevalence of several diseases on cattle farms in these regions, which can influence the quality of their dairy products. A large cluster of dairy cattle farmers treated their animals themselves, without help from veterinarians. These individuals had not received any training in milking hygiene. Training in good hygiene practices should be implemented for all farmers, and a rigorous follow-up of the application of these good practices should be carried out to improve the sanitary quality of the milk produced in these breeding areas.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

GK, AD, BM-TSO, PS, SF, JM, M-LS, and AC: conceptualization. GK, AD, and BM-TSO: methodology and investigation. IY: software and formal analysis. PS, PA, JH, JM, M-LS, AC, and SF: validation, writing—review and editing, and supervision. SF and AC: resources, project administration, and funding acquisition. GK, PS, JM, and SF: data curation. GK: writing—original draft preparation. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1050592/full#supplementary-material

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