

# Applicability of a simulated mathematical model for the production of pasteurized milk and yoghurt under experimental conditions

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## Abstract

The quality of dairy products in West Africa is compromised by the use of inappropriate raw milk collection and storage systems. The objective of this study was to apply a mathematical model for raw milk collection and storage developed in Burkina Faso with a view to improving the quality of raw milk and local dairy products from milk processing units. Using a modelled collection system, 32 liters of raw cow's milk were collected and stored (+4°C) from 48 dairy farms and six milk collection centres. They were grouped into four blocks or levels and located at a distance of 0-50 km from the center of Bobo-Dioulasso. After storage at +4°C, the raw milk was processed into pasteurised milk and yoghurt. These dairy products were tested for nutritional and microbiological parameters during 15 and 30 days of storage (+4°C) for pasteurised milk and yoghurt, respectively. Statistical methods focused on data description and Student's t-test using XLSTAT software. The results for stored raw milk showed variable pH (6.94 to 6.80), dry matter (15.99% to 18.10%), fat (2.98% to 4.76%), protein content (3.72% to 4.01%) and density (1.028 to 1.030). The microbiological results show a total aerobic count of  $3.6 \times 10^1$  CFU/mL in pasteurised milk and the absence of thermotolerant coliforms, *Staphylococcus aureus*, yeasts and moulds in yoghurt and pasteurised milk. It can be concluded that modelling the collection and storage system can enable the production of dairy products of better nutritional and sanitary quality for consumers.

**Keywords:** milk, mathematical model, collection, yoghurt, pasteurized milk.

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# Applicabilité d'un modèle mathématique simulé pour la production du lait pasteurisé et du yaourt en conditions expérimentales.

## Résumé

L'objectif de cette étude était d'appliquer un modèle mathématique de collecte et de conservation du lait cru développé au Burkina Faso en vue d'améliorer la qualité du lait cru et des produits laitiers locaux des unités de transformation laitière. A partir d'un dispositif de collecte modélisé, 32 litres de lait cru de vache ont été collectés et conservés à +4°C, auprès de 48 élevages laitiers et de 06 centres de collecte de lait. Ils étaient regroupés en 04 blocs et situés entre 0-50 km par rapport au centre-ville de Bobo-Dioulasso. Après conservation, le lait cru a été transformé en lait pasteurisé et yaourt. Ces produits ont été contrôlés pour les paramètres nutritionnels et microbiologiques durant 15 et 30 jours de conservation (+4°C) respectivement pour le lait pasteurisé et le yaourt. Les méthodes statistiques ont porté sur la description des données, le test de Student grâce au logiciel XLSTAT. Les résultats du lait cru ont montré un pH (6,94 à 6,80), une matière sèche (15,99% à 18,10%), des matières grasses (2,98% à 4,76%), des matières protéiques (3,72% à 4,01%) et une densité (1,028 à 1,030) variables. Les résultats microbiologiques donnent une flore totale de  $3,6 \times 10^1$  UFC/mL dans le lait pasteurisé et l'absence de coliformes thermotolérants, de *Staphylococcus aureus*, de levures et de moisissures dans le yaourt et le lait pasteurisé. On peut conclure que la modélisation du dispositif de collecte et de conservation peut permettre de fabriquer des produits laitiers de meilleure qualité nutritionnelle et sanitaire pour les consommateurs.

**Mots clés :** lait, modèle mathématique, collecte, yaourt, lait pasteurisé

## Introduction

Agro-pastoral activities employ approximately 75% of the rural population in Burkina Faso. (INSD, 2020). This sector is the hub of the national economy, with livestock farming contributing more than 12% of gross domestic product, particularly dairy production (BERD, 2010). The national milk production potential is estimated at 60 liters of milk per goat per year and 110 liters per cow per year for 3,095,730 goats and 1,968,000 lactating cows, respectively (MRAH/DGESS, 2021). However, poor management of this significant dairy supply has led to a milk deficit that is being filled by imports of powdered milk (CORNIAUX, 2013). The government is therefore supporting the creation of milk processing units (MPU) and milk collection centers (MCL) to develop the sector. However, only 10% of the milk produced each year is collected for processing (TRAORE *et al.*, 2022a).

The main suppliers of raw cow's milk to MPUs are MCLs, followed by a few farms in peri-urban areas. Milking hygiene, the condition of collection containers and transport conditions are obstacles to milk collection. Added to this is the failure of the milk storage system in MPUs, which affects the quality of the finished products. Could mathematical modelling of the raw milk collection and storage system be a solution for improving the quality of dairy products in Burkina Faso?

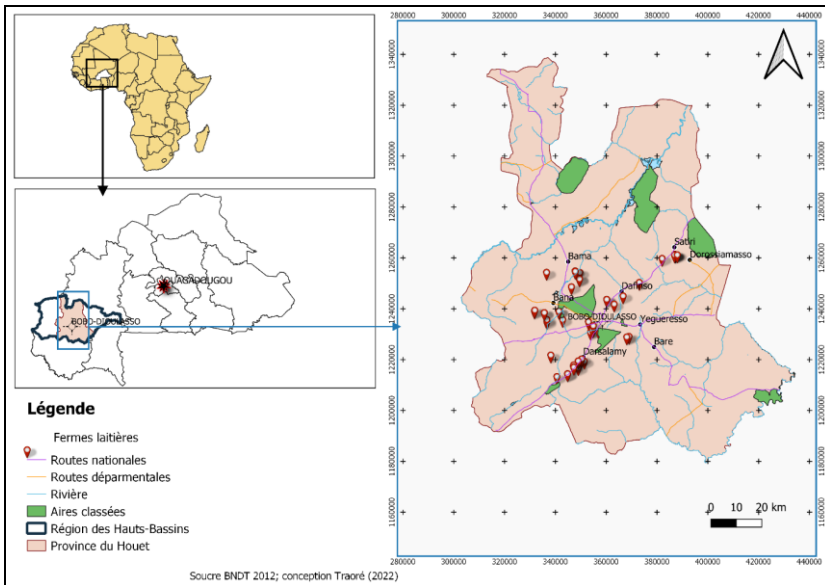
The group or individual collection system using rudimentary means and the milk collection system using pick-up trucks have been developed since 2008 in several West African countries (DIA *et al.*, 2009). These collection systems have encountered numerous difficulties related to the equipment used (containers, means of transport), which do not allow for the collection of larger volumes or compliance with transport and storage conditions (DIA *et al.*, 2009). This led to the creation of multi-service farmer collection centers in Mali and Niger (TEHEUX and VAN TROOS, 2019). These new players in the local milk sector provide not only collection, but also marketing, livestock feed supply and technical support. Although this collection system helps to establish links between producers and manufacturers, it faces constraints related to milk pricing, insufficient collection quantities and long milk transport times (PASMEP, 2016). Furthermore, none of these systems has been mathematically modelled in West Africa to resolve some of these constraints, which undoubtedly impact the quality of milk and dairy products. Furthermore, a mathematical model has been proposed for the Moroccan dairy industry, but this model is limited to the multi-site, multi-product logistics chain (TOUIL *et al.*, 2015). The same limitation was observed in Europe (Slovakia) for the mathematical model designed to optimise milk production on farms (ZÁHRADNÍK *et al.*, 2018). However, Geary *et al.* (2010) went further by developing a model for the Irish dairy industry that takes into account milk collection, product manufacturing and standardisation. For our part, the application of a mathematical model integrating milk collection and storage would be the foundation for the harmonisation and standardisation of manufacturing processes for competitive local dairy products in Burkina Faso and West Africa. The objective of this study was to apply a mathematical model of raw milk collection and storage developed in Burkina Faso with a view to improving the quality of milk and local dairy products from milk processing units (MPUs). The

hypothesis to be confirmed is as follows: the application of the mathematical model for raw milk collection and storage improves the nutritional and sanitary quality of pasteurised milk and yoghurt.

## I. Materials and methods

### I.1. Study area

This study was carried out in the city of Bobo-Dioulasso and its peri-urban area over the period November 2022 to January 2023 (Fig. 1) This area is the largest producer (2/3) of milk in the western dairy basin. Milk suppliers were selected according to four criteria (distance, geographical location, cow breeds and nature of farms) described in previous work (TRAORE, 2024).



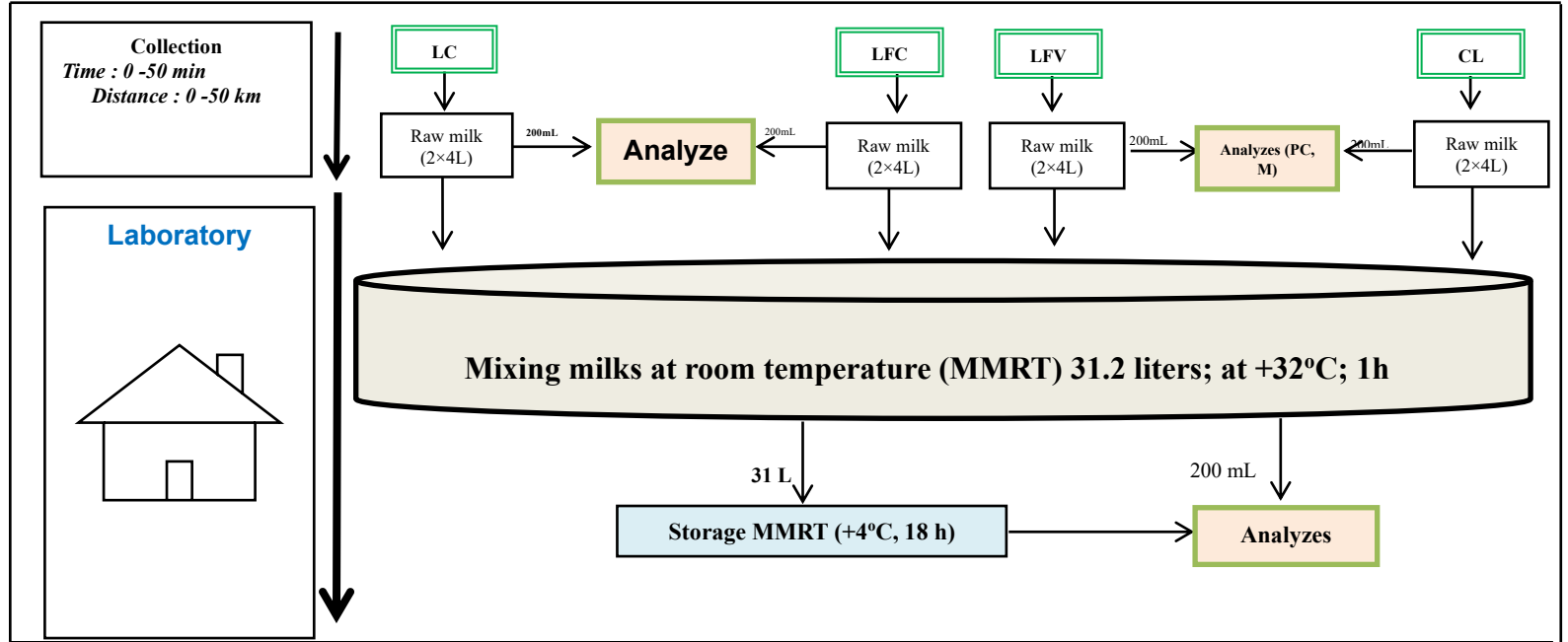
**Fig 1** Geolocation of dairy farms and milk collection centers located. They are located within a radius of 0 to 50 km of the center of Bobo-Dioulasso, which is the capital of the Houet province shown in pink.

### I.2. Application of the mathematical collection model in experimental situations in the laboratory.

#### I.2.1 Reproduction of the collection and storage system in the laboratory

The modelled system was applied to 54 suppliers grouped into four levels or origins of milk, namely: cow level (LC), choice farm level (LFC), voluntary farm level (LFV) and collector level (CL). The LC

consisted of 16 dairy cows, including eight local breeds and eight crossbred cows. These cows belonged to traditional and semi-improved farms. The LFC comprised farms defined as such by a laboratory team that visited them to carry out controlled sampling during milking. There were 16 such farms, both traditional and semi-improved, which were different from those where the LC and LFV cows came from. The LFV group consists of farms that voluntarily agreed to deliver their milk themselves to the laboratory in accordance with the model. There were 16 traditional and semi-improved farms, different from those where the LC cows came from. For the CL, six milk collection centers (MCLs in Bama, Bana, Farako-Bâ, Dafinso, Satiri and Yégérésso) were selected. Sampling was organized over eight collection days with a one-week collection interval, corresponding to eight repetitions. For each collection day, two raw milk samples were collected per level, with a volume of 04 liters per sample, either eight liters of milk collected for each level. The distance intervals (0–50 km) and travel times (10–50 min) predefined by the mathematical simulation were applied (TRAORE, 2024). Initial analyses were carried out on each sample of raw milk by level before they were mixed. Milk mixing and analysis were carried out according to the author's method (Fig. 2). The analyses focused on the parameters taken into account in the model (pH, fat and protein content, dry matter and total aerobic count).



**LC:** cow level, **LFC:** choice farm level, **LFV:** voluntary farm level, **CL:** collector level, **PC:** chemicals (pH, fat, protein content, dry matter, density), **M:** microbiological (total aerobic count, *Staphylococcus aureus*, thermotolerant coliforms).

**Fig. 2** Raw milk collection and storage system (TRAORE *et al.*, 2022a). This illustration shows, firstly, the technique for collecting raw cow's milk from the four levels (LC, LFE, LFV and C). Secondly, it shows the mixing of milk at room temperature (MMRT) and the storage of MMRT at 4°C. Finally, it shows the steps involved in taking aliquots (200 mL) and performing physical-chemical (PC) and microbiological (M) analyses. This procedure corresponds to one day of collection or sampling, repeated eight times.

## I.2.2. Processing of raw cow's milk from the system

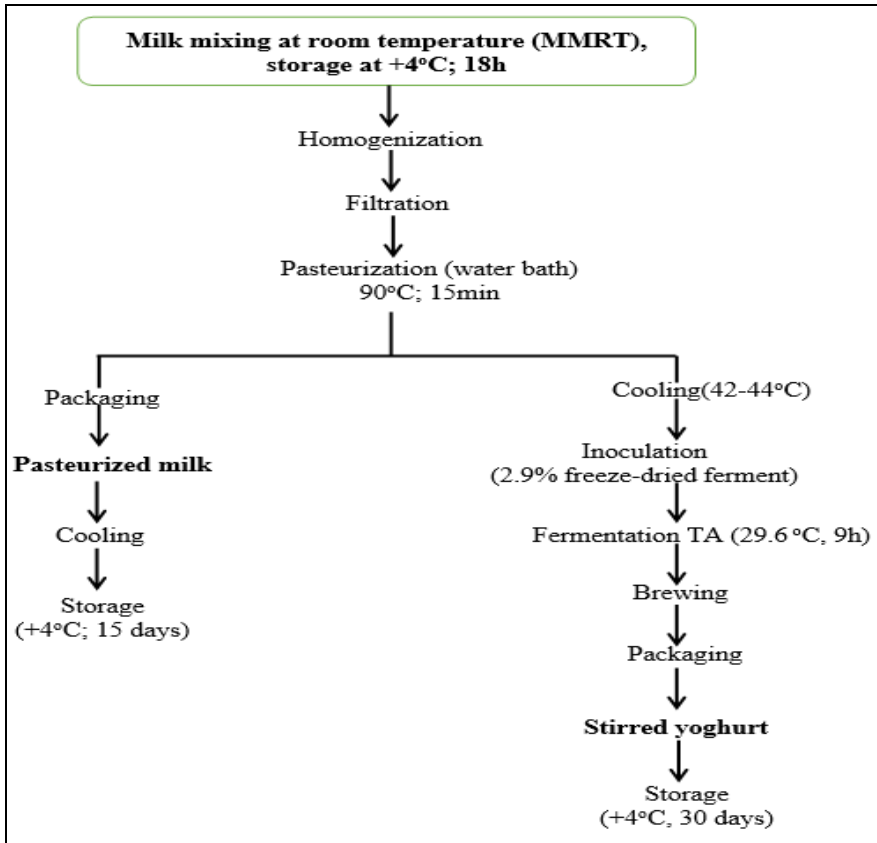
The processing of the milk collected (MMRT) according to the system takes place the day after collection in order to incorporate the effect of temperature on the milk. Processing involved the manufacture of pasteurized milk and yoghurt. These were kept in the refrigerator at +4°C to monitor chemical and microbiological parameters for 15 and 30 days respectively for pasteurized milk and yoghurt. The manufacturing stages were as follows (Fig. 3):

**Filtration:** after 18 h storage at +4°C and sampling, the remaining quantity of mixing milk (MMRT) was 30 liters. This volume was first homogenized before undergoing a series of filtration operations using a sieve covered with white cloth. This removed impurities from the milk before pasteurization;

**Pasteurization:** this consisted of a moderate but effective heat treatment in a water bath to eliminate all pathogenic micro-organisms. The filtered milk was heated to 90°C for 15 min. At the end of this time, 15 liters were taken for yoghurt production and the rest for fresh pasteurized milk. To this end, two manufacturing processes were followed (Fig. 3):

**Manufacture of pasteurized milk:** after pasteurization at (90°C/15min), the milk is immediately packaged in 500ml bottles and 50ml sterile plastic jars. They are then cooled in water containing ice before being kept in the fridge at +4°C for 15 days for quality control;

**Yoghurt production:** after pasteurization (15 liters), the milk was cooled to 42°C before being inoculated with 2.9% Lyobac C-D freeze-dried ferment containing *Lactobacillus bul-graicus* and *Streptococcus thermophilus*. The mixture was then left to ferment at room temperature of 29.6°C for 9 h. At the end of this time, the firm yoghurt obtained was stirred using a disinfected beater, resulting in stirred yoghurt. This is then packaged in sterile jars that have been kept at +4°C for 30 days to monitor bacteriological and nutritional quality.



**Fig. 3** Production diagram for pasteurized milk and yoghurt from milk collected using the mathematical collection and model. This diagram shows the artisanal production of yoghurt and pasteurised milk. On the right are the steps involved in producing pasteurised milk, and on the left are those involved in producing yoghurt.

### **I.3. Monitoring changes in chemical and microbiological parameters of pasteurized milk and yoghurt stored at +4°C**

Monitoring took place over 15 days for pasteurized milk and 30 days for yoghurt, with a frequency of five days for each product. Every five days from the date of manufacture, a sample of each product was taken for the analysis's chemical and microbiological.

#### **Chemical analysis**

The pH was measured in 100 mL samples (raw milk, yoghurt and pasteurized milk) using a pH meter (370 pH Meter Jenway, European Union) (AKABANDA *et al.*, 2010). The infrared spectroscopy method (Dairy Milk Analyser, DMA, 2001, Miris AB, Sweden) was used to determine the fat (FM), protein content (PM) and dry matter (DM) content of raw milk (MILLOGO, 2010; SISSAO, 2018). In particular, the FM content of yoghurt and pasteurized milk was determined by hexane extraction using a Soxhlet extractor in accordance with the international standard (ISO-659, 1998). Their dry matter content was then determined by weighing the difference between 5 g of the sample before and after passing it through an oven at  $105^{\circ}\text{C} \pm 2^{\circ}\text{C}$  for 3 h (NF V03-707, 2000). In addition, the lactic acid content of the yoghurt was determined using the volumetric titration method with 0.094N NaOH (AKABANDA *et al.*, 2010). The temperatures in the laboratory and refrigerators were measured using analogue probe thermometers (Digital Indoor/Outdoor Thermometer 64 T9234 0E-04).

### **Microbiological analysis**

The count covered total aerobic count (TAC), *Staphylococcus aureus*, thermotolerant coliforms, yeasts and moulds (YM) and lactic acid bacteria (LAB). A decimal cascade dilution was performed using 1 mL of the sample. 1 mL of the dilutions was inoculated deep or on the surface, depending on the parameter and the nature of the sample. The TAC count was performed on Plat Count Agar (PCA) after incubation at  $30^{\circ}\text{C}$  for  $72 \pm 3$  h (ISO 4833, 2013). *Staphylococcus aureus* counting was possible after incubation at  $37^{\circ}\text{C}$  for 24 to 48 h on Baird Parker (BP) agar supplemented with egg yolk and potassium tellurite (ISO 6888-2, 1999). Thermotolerant coliforms were counted on Lactose Agar with Crystal Violet and Neutral Red (VRBL) after incubation at  $44^{\circ}\text{C}$  for  $24 \pm 3$  h (NF V 08-060, 2009). Yeasts and moulds were counted on Sabouraud Chloramphenicol medium after incubation at  $+25^{\circ}\text{C}$  for  $72 \pm 3$  h (ISO 21527-1, 2008). The total lactic acid bacteria count was performed on selective MRS (Man Rogasa and Sharp) agar following incubation at  $+37^{\circ}\text{C}$  for 24 to 72 h in anaerobic jars (ISO 15214, 1998).

### **I.4. Mathematical and statistical analysis of the data**

Physico-chemical and microbiological data were subjected to descriptive statistics using XLSTAT software version 2016. Means were compared using the Student test (T-test) and differences were

considered significant at the probability threshold  $p \leq 0.05$ .

## II. Results

### II.1. Raw milk collection and storage parameters for the application of the model

It takes about an hour to transport milk from the volunteer farms to the laboratory over a distance of 27 km. The experimental farms, on the other hand, are closer to the laboratory (18 km) and can therefore be reached in around thirty min (Table I).

**Table I:** Collection and storage parameters for milk collected by level

| Origins of milk             | Distance (km) | Transport time (min) | Quantity (Liter) | Shelf life (h) at +4°C |
|-----------------------------|---------------|----------------------|------------------|------------------------|
| LC                          | 20            | 40                   | 08               |                        |
| LFC                         | 18            | 35                   | 08               |                        |
| LFV                         | 27            | 51                   | 08               |                        |
| CL                          | 23            | 43                   | 08               |                        |
| <b>MMRT (LC+LFC+LFV+CL)</b> |               |                      | 31               | 18                     |

*LC: cow level, LFC: choice farm level, LFV: voluntary farm level, CL: collector level, MMRT: mixing milk at room temperature.*

### II.2. Chemical values of raw cow's milk

Table II gives the average physicochemical composition of the raw milks from the four collection levels (LC, LFC, LFV, CL) as well as the composition of the mixing milk (MMRT). There was a non-significant variation in the pH (6.82 to 6.94) and density (1.028 to 1.030) of the milks between the different levels. The LFV and LFC levels had the highest levels of dry matter (18.10% and 17.93%), fat (4.76% and 4.49%) and protein (3.85% and 4.01%). The composition of the blended milk (MMRT) remained almost constant after storage at +4°C for 18 h.

### II.3. Microbiological values of raw cow's milk

The microbiological values show an absence of *Staphylococcus aureus* in the milk samples and of thermotolerant coliforms in the cow milk (LC). On the other hand, milk collected from choice farms (LFC) had the highest TAC (6.52 Log<sub>10</sub> CFU/mL) and thermotolerant coliforms (6.88 Log<sub>10</sub> CFU/mL) values. The microbial load of the blended milks

(MMRT, MMRT4°C) remained unchanged after storage (Table II).

**Table II:** Chemical and microbiological composition of raw milk collected and preserved using the mathematical model

| Origin of milk   | LC                       | LFV                       | LFC                       | CL                       | MMRT                    | MMRT4°C                  |
|--|--------------------------|---------------------------|---------------------------|--------------------------|-------------------------|--------------------------|
| <b>Parameters</b>                                      |                          |                           |                           |                          |                         |                          |
| <b>Chemical values</b>                                 |                          |                           |                           |                          |                         |                          |
| <b>pH</b>  | 6.94±0.06 <sup>a</sup>   | 6.80±0.10 <sup>a</sup>    | 6.87 ± 0.02 <sup>a</sup>  | 6.82 ± 0.04 <sup>a</sup> | 6.86 ± 0.2 <sup>a</sup> | 6.85 ± 0.02 <sup>a</sup> |
| <b>Dry matter (%)</b>                                  | 15.99±0.46 <sup>a</sup>  | 18.10 ± 0.39 <sup>b</sup> | 17.93 ± 1.24 <sup>c</sup> | 17.02±0.76 <sup>d</sup>  | 16.7 ± 0.3 <sup>a</sup> | 17.44 ± 0.1 <sup>c</sup> |
| <b>Fat (%)</b>   | 2.98 ± 0.41 <sup>a</sup> | 4.76 ± 0.35 <sup>b</sup>  | 4.49 ± 0.73 <sup>c</sup>  | 3.75 ± 0.04 <sup>d</sup> | 3.64±0.02 <sup>d</sup>  | 3.95±0.06 <sup>d</sup>   |
| <b>Proteins (%)</b>                                    | 3.72 ± 0.19 <sup>a</sup> | 3.85 ± 0.03 <sup>b</sup>  | 4.01 ± 0.46 <sup>c</sup>  | 3.78 ± 0.04 <sup>a</sup> | 3.83±0.01 <sup>a</sup>  | 3.95±0.03 <sup>b</sup>   |
| <b>Density</b>   | 1.028 ±0.00 <sup>a</sup> | 1.03 ± 0.00 <sup>a</sup>  | 1.030 ± 0.00 <sup>a</sup> | 1.029±0.00 <sup>1a</sup> | 1.028±0.0 <sup>0a</sup> | 1.028±0.0 <sup>0a</sup>  |
| <b>Microbiological values (Log<sub>10</sub>CFU/mL)</b> |                          |                           |                           |                          |                         |                          |
| <b>TAC</b>   | 5.6 ± 0.53 <sup>a</sup>  | 6.38± 0.38 <sup>b</sup>   | 6.52 ± 0.39 <sup>b</sup>  | 6.21 ± 1.10 <sup>b</sup> | 6.36± 0.2 <sup>b</sup>  | 6.65± 0.12 <sup>b</sup>  |
| <b>S. aureus</b>                                       | 00 ± 00 <sup>a</sup>     | 00 ± 00 <sup>a</sup>      | 00 ± 00 <sup>a</sup>      | 00 ± 00 <sup>a</sup>     | 00 ± 00 <sup>a</sup>    | 00 ± 00 <sup>a</sup>     |
| <b>CT</b>  | 00 ± 00 <sup>a</sup>     | 5.98 ± 0.85 <sup>b</sup>  | 6.88 ± 0.99 <sup>c</sup>  | 5.55 ± 0.92 <sup>d</sup> | 5.00± 0.1 <sup>b</sup>  | 6.02± 0.4 <sup>b</sup>   |

Values with the same superscript letter in the same line are not statistically different at the  $p > 0.05$  threshold according to Student (T-t). **LC:** cow level, **LFC:** choice farm level, **LFV:** voluntary farm level, **CL:** collector level, **MMRT:** mixing milk at room temperature, **MMRT4°C:** mixing milk at room temperature stored at +4°C. **TAC:** total aerobic count, **S. aureus:** *Staphylococcus aureus*, **TC:** thermotolerant coliforms.

## II.4. Chemical and microbiological values of dairy products from the model

### chemical values of products from the model

The results in Table III represent the chemical values of the yoghurt and pasteurized milk samples from the model. The pH (4.6 to 3.95) and fat content (3.75 to 2.96) of the yoghurt decreased slightly as a function of storage time, while at the same time the acidity gradually increased from 57 to 83°D. The dry matter content (DM) remained constant until the 30th day. The dry matter (DM) content remained

constant until the 30<sup>th</sup> day. However, this parameter (DM) decreases progressively from day 5<sup>th</sup> in pasteurized milk. This non-significant regression was also observed for pH and fat content in this milk product.

## **II.5. Microbiological values of dairy products from the model**

The results in Table III show an absence of *Staphylococcus aureus*, thermotolerant coliforms, yeasts and moulds in the yoghurt for 30 days. The proportion of lactic acid bacteria ( $10^8$  CFU/mL) also remained unchanged up to the expiry date. The TAC level in pasteurize milk samples decreased with time. It went from  $3.6 \times 10^1$  CFU/mL on the first day to 02 CFU/mL after 15 days. However, no colonies of *Staphylococcus aureus* or thermotolerant coliforms were found in the pasteurize milk samples (Table III).

**Table III:** Changes in the nutritional and microbiological values of samples of pasteurized milk and yoghurt (stored at +4°C) made from milk collected and stored using the mathematical model

| Analysis days                 | Samples               |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                        |                       |                        |
|-------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|------------------------|-----------------------|------------------------|
|                               | Yoghurt               |                       |                       |                       |                       |                       |                       |                       | Pasteurize milk       |                       |                       |                        |                       |                        |
|                               | 01                    | 05                    | 10                    | 15                    | 20                    | 25                    | 30                    | 01                    | 05                    | 10                    | 15                    |                        |                       |                        |
| <b>Parameters</b>             |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                        |                       |                        |
| <b>Nutritional values</b>     |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                        |                       |                        |
| <b>pH</b>                     | 4.6±0.0 <sup>a</sup>  | 4.5±0.2 <sup>a</sup>  | 4.44±0.6 <sup>a</sup> | 4.04±0.4 <sup>b</sup> | 4.00±0.1 <sup>b</sup> | 4.00±0.6 <sup>b</sup> | 3.95±0.2 <sup>c</sup> | 6.7± 0.2 <sup>a</sup> | 6,5± 0.1 <sup>a</sup> | 6.4± 0.6 <sup>a</sup> | 6.4±0.8 <sup>a</sup>  |                        |                       |                        |
| <b>Fat (%)</b>                | 3.7± 0.1 <sup>a</sup> | 3.6±0.5 <sup>a</sup>  | 3.3± 0.1 <sup>b</sup> | 3.3± 0.3 <sup>b</sup> | 3.2± 0.2 <sup>b</sup> | 3 ± 0.5 <sup>b</sup>  | 2.9±0.2 <sup>c</sup>  | 3.6± 0.1 <sup>a</sup> | 3.5± 0.8 <sup>a</sup> | 2.8± 0.2 <sup>b</sup> | 2.6±0.4 <sup>b</sup>  |                        |                       |                        |
| <b>Dry matter (%)</b>         | 13.9±0.6 <sup>a</sup> | 13.7±0.3 <sup>a</sup> | 13.5±0.4 <sup>a</sup> | 13.5±0.7 <sup>a</sup> | 13.3±0.3 <sup>a</sup> | 13.3±0.0 <sup>a</sup> | 13.2±0.1 <sup>a</sup> | 15.6±0.7 <sup>a</sup> | 14.1±0.5 <sup>b</sup> | 13.8±0.4 <sup>c</sup> | 13.7±0.2 <sup>c</sup> |                        |                       |                        |
| <b>Acidity (°D)</b>           | 57±0.4 <sup>a</sup>   | 59.5±0.2 <sup>b</sup> | 60.1±0.8 <sup>c</sup> | 61±0.1 <sup>c</sup>   | 75.5±0.4 <sup>d</sup> | 76±0.1 <sup>d</sup>   | 83±0.7 <sup>e</sup>   |                       |                       |                       |                       |                        |                       |                        |
| <b>Microbiological values</b> |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                       |                        |                       |                        |
| <b>S. aureus (CFU/mL)</b>     | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   |                        |                       |                        |
| <b>TC (CFU/mL)</b>            | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   |                        |                       |                        |
| <b>LM (CFU/mL)</b>            | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   | 00± 00 <sup>a</sup>   |                       |                       |                       |                       |                        |                       |                        |
| <b>LAB (CFU/mL)</b>           | 2.6×10 <sup>8</sup>   | 4.1×10 <sup>8</sup>   | 3.1×10 <sup>8</sup>   | 5.4×10 <sup>8</sup>   | 4.4×10 <sup>8</sup>   | 5.6×10 <sup>8</sup>   | 8.4×10 <sup>8</sup>   | ±0.1×10 <sup>8a</sup> | ±0.3×10 <sup>8b</sup> | ±0.0×10 <sup>8c</sup> | ±0.4×10 <sup>8d</sup> | ±0.2×10 <sup>8a</sup>  | ±0.3×10 <sup>8d</sup> | ±0.0× 10 <sup>8e</sup> |
| <b>TAC (CFU/mL)</b>           |                       |                       |                       |                       |                       |                       |                       | 3.6×10 <sup>1</sup>   | 1.4×10 <sup>1</sup>   | 1.7×10 <sup>1</sup>   | 02± 0.2 <sup>d</sup>  | ±0.6× 10 <sup>1a</sup> | ±0.3×10 <sup>1b</sup> | ±0.4×10 <sup>1c</sup>  |

Values with the same superscript letter in the same line and for the same samples are not statistically different at the  $p > 0.05$  threshold according to Student (T-t) °D: dornic degree, TAC: total aerobic count; S. aureus: Staphylococcus aureus; TC: thermotolerant coliform.

### III. Discussion

The application of the mathematical model by TRAORE *et al.* (2024) was included three main stages: collection and preservation, processing and quality control of dairy products.

#### III.1. Collection and storage of raw milk at +4°C

The milk was collected from four main levels (LC, LFC, LFV, and CL) at distances of between 18 and 27 km for transport times of between 35 and 51 min (Table I). Milks mixed at room temperature (MMRT) were stored for 18 h at +4°C. These results are in line with previous work by TRAORE *et al.* (2022a). Who found mean values of 23 km, 43 and 18 h respectively for distance, transport time and shelf life. In addition, these authors had carried out eight days of collection for a quantity of 2 liters of milk per day. This is contrary to the number of days (one day) and the quantity (eight liters) of milk in the present study. It was deduced that the number of collection days and the quantity of milk did not lead to any change in the collection system. Furthermore, the collection and conservation results (Table I) fall within the ranges defined (simulation results: optimum parameters) by the mathematical model. The milks were also subjected to chemical and bacteriological analyses during collection and after storage. Table II shows a non-significant difference ( $p > 0.05$ ) between the pH values (6.82 to 6.94) of the collection milks up to the end of storage. Milks from the same area had given lower pH values of between 6.37 and 6.77 (MILLOGO *et al.*, 2018; TRAORE *et al.*, 2022a). These high pH values in the present study indicate low biochemical and bacterial metabolism in milk, which are responsible for milk acidification (BURKE *et al.*, 2018). This can also be explained by compliance with milking and collection hygiene (TRAORE *et al.*, 2022b). The results for density (1.028 to 1.030) show the same trend as those for pH at the threshold of  $p > 0.05$  (Table II). Similar densities were found in Morocco and Tunisia (TAYBI *et al.*, 2014; M'HAMDI *et al.*, 2018). The highest fat and protein content levels were observed in milk collected by controlled sampling (LFC) and milk delivered to the laboratory by farmers (LFV). However, a significant variation ( $p < 0.05$ ) in the levels of fat ( $2.98 \pm 0.41$  to  $4.76 \pm 0.35\%$ ) and protein ( $3.72 \pm 0.19$  to  $4.01 \pm 0.46\%$ ) was observed between samples from different levels. This fat rate is in line with those recommended (2.8 to 3.2%) by AFNOR (2001). MILLOGO (2010), found similar levels of protein content (3 to 3.9%) in Burkina Faso to those found in the

present study. These analyses show that the results of the chemical analysis of this work are superior to those found by the same authors during the development of the collection system (TRAORE *et al.*, 2022a).

Bacteriological analysis of the milks gave an inconsistent TAC (total aerobic count) value in the range  $3.9 \times 10^5$  to  $3.3 \times 10^6$  CFU/mL (Table II). These values are close to those ( $3 \times 10^5$  CFU/mL) in the universal standard (ISO 4833-1, 2013). Previous studies have found higher values of between  $10^6$  and  $10^7$  CFU/mL (HAMIROUNE *et al.*, 2014; SEME *et al.*, 2015; COULIBALY *et al.*, 2020; COMPAORE *et al.*, 2021; TRAORE *et al.*, 2022b). The study revealed levels of thermotolerant coliforms ( $3.5 \times 10^6$  to  $7.6 \times 10^7$  CFU/mL) that did not comply with international regulations (NF V 08-060, 2009), which set a maximum value of  $10^3$  CFU/mL. Coliform contamination of milk is thought to be of faecal origin during milking and milk collection. In addition, the use of rudimentary containers can be a source of contamination. (MILLOGO, 2010; SISSAO, 2018; TRAORE *et al.*, 2022b). On the other hand, no contamination of the milk samples by *Staphylococcus aureus* was observed (Table II), which implies an absence of mastitis in the cows. However, the temperature and storage time (+4°C and 18 h) did not induce a major change in the bacterial load of the milk (MMRT4°C). So, to reduce this load, heat treatment was necessary on the one hand, and on the other, to check the suitability for processing of milk from different origins mixed and stored for a long time.

## **II.2. Processing of milk collected and stored at +4°C**

The unit operations (filtration, homogenization, pasteurization, packaging, cooling) were carried out as described in the good hygiene practice guide (GRET/IPROLAIT, 2020) and the work of MILLOGO-DAH *et al.* (2019). Fig. 3 shows a pasteurization temperature of 90°C for 15 min, which is in line with the values prescribed (temperature: 80-95°C; time: 10-15 min) by the guide and those found in dairies in Burkina Faso by MILLOGO-DAH *et al.* (2019) and TRAORE *et al.* (2022b). The scales used in this study indicate high pasteurization, which would be sufficient to destroy almost all pathogenic and common flora, but also to preserve the nutritional and organoleptic quality of the milk (GHAZI and NIAR, 2011). In addition, hot packaging of pasteurized milk eliminates any micro-organisms contained in the packaging (Fig. 3). As for yoghurt production, the

freeze-dried ferment used would be composed of *Streptococcus thermophilus* and *Lactobacillus bulgaricus* spp. The proportion was defined according to local realities and not the manufacturer's instructions (0.024g per liter) (Lyobac C-D). Thus, 0.06g were required to ferment 1 liter of milk at an ambient temperature of 29.6°C for 6h. Previous studies have shown lower proportions of 2 to 3% (MILLOGO-DAH *et al.*, 2019; TRAORE *et al.*, 2022b). However, the efficiency of milk processing would be verified by monitoring the physicochemical and microbiological parameters of the pasteurized milk and yoghurt obtained.

### II.3. Quality control of dairy products

It has carried monitoring changes in the chemical and microbiological parameters of pasteurized milk and yoghurt stored at +4°C for 15 and 30 days respectively. The results of the chemical analysis show a pH of the yoghurt varying between 4.6 and 3.95 during storage (Table III). However, the high pH values (4.6 to 4.44) were observed from the first 10 days of storage, followed by a gradual decrease from 4.04 to 3.95 from the 20<sup>th</sup> to the 30<sup>th</sup> day of storage. These results are similar to those found in Congo, where the pH varied from 4.38 to 4.25 during 14 days of storage at +4 to +6°C (KASAMBA *et al.*, 2019). Other authors have reported a decrease in pH from 4.5 to 4.00 over a storage period of 21 to 28 days (ZARE *et al.*, 2011; SILVA *et al.*, 2014). Table III also shows us that the decrease in pH results in an increase in yoghurt acidity (57 to 83 °D). These remarks were also relayed by KASAMBA *et al.* (2019) and SILVA *et al.* (2014). This increase is due to the transformation of residual lactose into lactic acid by *Streptococcus thermophilus* and *Lactobacillus bulgaricus* (MULTAG and HASSANN, 2008; ABDALLA and ABDEL NABI, 2010). The fat content of the yoghurt varied between 3.75% and 2.96% during storage, whereas the dry matter content remained stable up to the expiry date. The decrease in fat content was noticeable from day 15 to day 30. These fat levels are comparable to previous studies (NGASSAM, 2007; KASAMBA *et al.*, 2019), which found fat percentages of between 3.6 and 3.3% but variable dry matter levels (12.4 to 11.8%), which are therefore different from our results. The pH, fat and dry matter of the pasteurized milk varied significantly over the 15 days of storage from 6.71 to 6.44 to 6.71; 3.6 to 2.65% and 15.63 to 13.71% respectively. The lowest values for pH (6.46 to 6.44), fat (2.86 to 2.65%) and DM (13.82 to 13.71%) were observed from the 10<sup>th</sup> day of storage. The pH and dry matter results comply

with AFNOR regulations, which set 6.55 to 6.66 and 8 to 13% respectively. On the other hand, SISSAO *et al.* (2015) had obtained in Burkina Faso an approximate pH (6.4 to 6.6) in pasteurized milk and a dry matter (11 to 13.29%) lower than the values obtained during this study. On the other hand, the fat content (3 to 4.38%) found by these authors is higher than these results as well as those found (3 to 4.4%) in Mauritania in pasteurized milk (OULD *et al.*, 2012). The microbiological analysis results (Table III) for yoghurt and pasteurized milk give an absence of *Staphylococcus aureus* as in raw milk. These results are similar to those obtained by SISSAO *et al.* (2015). In addition, no thermotolerant coliform colonies (yoghurt and pasteurized milk), yeasts or moulds (yoghurt) were observed in the samples during storage. This testifies to the effectiveness of the pasteurization process, which eliminated these contaminating germs at the chosen temperatures (90°C; 15 min). The absence of these microbial contaminants was also noted in yoghurts during 14 days of storage at +4-6°C by KASAMBA *et al.* (2019). However, Table III shows the presence of TAC (Total Aerobic Count) in pasteurized milk samples, with values decreasing from  $3.6 \times 10^1$  to 2 CFU/mL during 15 days of storage. These values are in line with the Algerian standard (JORA, 1998) which recommends  $3 \times 10^4$  CFU/mL but also with the work of FAWZIA *et al.* (2016). The lactic ferments in yoghurt must be abundant in the finished product (CODEX STAN-243, 2003) and, thanks to their antibacterial activity, inhibit the growth of pathogenic germs. These assertions corroborate the results of analyses of *Streptococcus thermophilus* and *Lactobacillus bulgaricus* in yoghurt samples (Table III). There was little variation ( $2.6$  to  $8.4 \times 10^8$  CFU/mL) in these lactic bacteria over a 30 days storage period at +4°C. These results are in line with ISO 15214 regulations (minimum  $10^6$  CFU/mL) on the one hand and different from 2 to  $63 \times 10^6$  CFU/mL on the other, results reported in the USA (North Carolina), Algeria and Congo (IBRAHIMA and CARR, 2006; ABDELMALEK *et al.*, 2009; KASAMBA *et al.*, 2019).

## Conclusion

The main obstacle to the revolution in the West African dairy industry for products that defy all competition is the failure to comply with general hygiene principles throughout the production and processing chain. From this work, the mathematical model for the collection and storage of raw milk has made it possible to control the hygiene of raw milk from collection to storage. It also shows that processing raw milk

stored at +4°C for 18 h according to the model produces pasteurised milk and yoghurt of better nutritional and sanitary quality, thus confirming the study's hypothesis. The quality of these products is satisfactory for up to 15 days of storage (+4°C) for pasteurised milk and 30 days for yoghurt. However, it would be necessary to use the model to improve the manufacturing technologies of other local products such as liquid gappal and dèguè in Burkina Faso. Finally, the model should be applied in a few dairies before its validation.

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## **Conflicts of interest**

The authors declare that they have no conflicts of interest in relation to this article.

## **Author's contributions**

ST was responsible for collecting and processing the data and writing the manuscript. MS contributed to the design of the experimental protocol and the drafting of the manuscript. VM approved the experimental protocol and contributed to the drafting and correction of the manuscript. He is the scientific supervisor of this study.

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