Food and Nutrition Sciences, 2025, 16(11), 1771-1787
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

Rennet Coagulation Time, Curd Firmness, Butter-Making Potential and Proximate Composition of Milk from Four Indigenous Cattle Breeds of Benin

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How to cite this paper: Tougan, U.P., Akpo, Y., Sale, L., Akpo, F.O.Y., Tohozin, R.A., Gounou N'Gobi, B., Mama, Y.T.I., Adjiwanou, C.R., Sindic, M., Beckers, Y. and Thewis, A. (2025) Rennet Coagulation Time, Curd Firmness, Butter-Making Potential and Proximate Composition of Milk from Four Indigenous Cattle Breeds of Benin. *Food and Nutrition Sciences*, **16**, 1771-1787.
https://doi.org/10.4236/fns.2025.1611104

Received: November 8, 2025
Accepted: November 24, 2025
Published: November 27, 2025

Abstract

Genetic factors can affect cheese and butter making abilities and nutritional composition of milk. The study aimed to assess the influence of breed on the technological and compositional qualities of milk from four indigenous cattle breeds of Benin (Borgou, N'Dama, Azawak, and Lagunaire breeds). A total of 10 L of milk per cow breed reared on natural pasture were analysed for rennet coagulation time, curd firmness, and butter-making potential using formagraph and AOAC methods. Data were processed with SAS software. Breed significantly affected ($P < 0.001$) milk coagulation behavior and related physicochemical traits. Borgou milk showed the shortest coagulation time (1.72 min), followed by N'Dama (2.25 min), Azawak (3.2 min), and Lagunaire (5.4 min), indicating faster coagulation and better cheesemaking aptitude in Borgou. Curd firming time (K20) differed ($P < 0.05$), with Borgou and Lagunaire firming faster than Azawak and N'Dama. Titratable acidity was slightly lower in Borgou ($P < 0.05$), while pH was higher in Azawak milk ($P < 0.001$). Breed also significantly influenced cheese- and butter-making potentials. Raw curd yield was highest in Borgou (0.36%), followed by Lagunaire (0.32%), N'Dama (0.30%), and Azawak (0.24%) ($P < 0.001$). Dry curd yield was higher in Borgou, N'Dama, and Lagunaire (59.73%, 59.2%, 59.4%) than in Azawak (47.65%)

($P < 0.001$). Ash content differed ($P < 0.05$), being higher in Azawak (0.8%) and Lagunaire (0.78%) than in Borgou and N'Dama (0.70%). Fat content varied significantly ($P < 0.001$), with Borgou (3.49%) and N'Dama (3.38%) richer than Azawak (2.74%) and Lagunaire (2.18%). Whey dry matter ranged from 11.2% (Azawak) to 13.08% (Lagunaire) ($P < 0.001$). Milk dry matter also varied ($P < 0.001$): Lagunaire (8.4%) and Borgou (7.6%) were richer than Azawak (7.73%) and N'Dama (6.51%). Protein content differed markedly ($P < 0.001$), being highest in Lagunaire (4.11%) and Azawak (3.66%), moderate in N'Dama (3.34%), and lowest in Borgou (3.15%). Overall, these results demonstrate that breed affects milk coagulation properties, acidity, pH, and composition. Borgou milk shows the best technological potential for cheese and butter production, followed by N'Dama and Lagunaire, while Azawak milk though richer in protein has lower curd yields and less favorable processing characteristics.

Keywords

Indigenous Cow Milk, Rennet Coagulation Time, Curd Firmness, Cheese Yield, Butter-Making Potential, Macronutrients, Benin

1. Introduction

Milk plays a vital role in global food security, nutrition, and technological innovation by providing essential nutrients, supporting rural livelihoods, and driving progress in agricultural and food-processing systems [1]. It is a primary source of high-quality proteins, calcium, and vitamins that contribute significantly to the prevention of malnutrition and the promotion of human health, particularly among vulnerable populations [1] [2]. Advances in dairy technology have further enhanced production efficiency, product safety, and the development of diversified dairy products, thereby meeting increasing global demand while addressing sustainability challenges [2] [3]. The composition of milk, particularly its protein fractions and fat content, together with genetic and environmental influences, exerts a strong effect on its technological performance, notably in cheese and butter manufacture [3]-[5]. Milk coagulation properties, which include rennet coagulation time, curd firming rate, and curd firmness, are critical indicators of milk suitability for cheese production [6] [7]. Variations in these properties are influenced by multiple factors, such as breed, feeding systems, and environmental conditions [8]. Studies across various regions have demonstrated that breed-specific differences significantly affect milk's coagulation behavior, curd firmness, and overall cheese-making efficiency [9]-[12]. Similarly, differences in fatty acid composition and physical properties of milk are known to influence butter yield and quality [13] [14].

In Benin, the dairy sub-sector plays a vital role in the national economy, contributing significantly to income generation, employment, rural livelihoods, and food and nutrition security [15]. Indigenous cattle breeds represent key elements of the country's cultural heritage, being deeply rooted in traditional practices and

social life, especially within rural communities of northern Benin. Their value also lies in sustaining ancestral customs and supporting the production of distinctive local foods such as the artisanal cheese Wagashi. Local dairy production in Benin predominantly relies on these native breeds [15] [16]. Milk from these animals is generally pooled and traditionally processed into Wagashi cheese without prior assessment of its technological suitability for cheese or butter production [16] [17]. Despite the cultural and economic importance of Wagashi in northern Benin, scientific information on the composition, coagulation behavior, and butter-making potential of milk from indigenous breeds remains scarce [18]-[20]. The local dairy systems are mainly based on natural grazing, with breeds such as Borgou, Azawak, N'Dama, and Lagunaire raised under comparable extensive management conditions [16] [21]. A better understanding of the technological characteristics and processing potential of milk from these breeds is essential to optimize traditional dairy processing, enhance Wagashi cheese and butter yields and quality, and promote the sustainable valorization of local genetic resources.

Therefore, this study aimed to assess the cheese and butter-making abilities, as well as the proximate composition of milk from four indigenous breeds (Borgou, Azawak, N'Dama, and Lagunaire) reared on natural pastures in Benin.

2. Material and Methods

2.1. Study Area

The study was conducted jointly at the university of Parakou and the Laboratory "Quality and Safety of Agro-Food Products" of Gembloux Agro-Bio Tech, University of Liège in Belgium, from May 1, 2017, to September 30, 2023. The milk from Borgou and Azawak cow breeds was sampled at Okpara Livestock Farm, located in Kika District (2˚39' - 2˚53'E longitude and 9˚6' - 9˚21'N latitude) of the Commune of Tchaourou, Borgou Department [22]. The milk from Lagunaire cow breed was sampled from the Lagunaire herds kept on natural pasture in the munipality of Savalou (Samiondji) in Benin. The Milk from N'Dama cow was collected from the herd reared on natural pasture in the Municipality of Djougou.

2.2. Milk Sampling and Data Collection

Data on the technological and nutritional properties of milk were collected from 10 liters of fresh milk obtained from 10 cows of each breed reared under identical conditions on natural pasture at the Okpara Livestock Farm. All cows were reared under natural pasture feeding. Each 1-liter sample was immediately chilled and transported to the laboratory, where it was individually analyzed for technological and nutritional properties without pooling.

The technical equipment included a thermometer, micropipettes, standard dairy glassware, standard laboratory glassware, a CRM (Computer Renneting Meter) for determining milk coagulation properties, a centrifuge, plastic bottles of 500 ml, 50 ml, and 10 ml, an analytical balance, a vortex mixer, a desiccator, a

water bath, titration devices, a Congo Red dye bottle, a Berthelot 530 rennet bottle, a thermometer, two sachets of concentrated lyophilized lactic starter cultures (DANISCO), 15 burettes, 12 beakers, a pack of pipettes, Kjeldahl glassware, a Kjeldahl apparatus, Kjeldahl catalyst tablets, a digester, a distiller, an acid-base titration setup, a phenolphthalein bottle, sulfuric acid, sodium hydroxide, distilled water, and Mojonnier fat-extraction flasks as specified in ISO 3889 [23] and described by [16].

Methodologically, the data collected included: milk coagulation time, curd firming time, titratable acidity, pH (hydrogen potential), fresh cheese yield, dry cheese yield, dry matter content of milk, dry matter content of whey, protein content, fat content, total mineral (ash) content, and potassium dichromate content.

Technologically, milk sample pH was measured using a pH meter previously calibrated with buffer solutions at pH 7 and 4 (±50 ml in a small beaker). The characteristics of milk coagulation (MCP) are commonly described using parameters such as rennet coagulation time (RCT), the time required to reach a curd firmness of 20 mm (k20), and the curd firmness measured 30 minutes after the addition of the coagulant (a30) [6]. These parameters (r and k20) were measured in the current study by using computerized renneting meters (Formagraph) as described by [23]. Laboratory cheese yield (fresh and dry) was determined by measuring the quantity of curd obtained after adding rennet to the milk. The potassium dichromate content was determined according to the French standard NF V 04-209 (October 1989), "Determination of the potassium dichromate content of milk: Reference method".

As for nutritional quality and butter-making potential of milk, dry matter, ash, fat, and protein contents were determined following the standardized procedures recommended by AOAC [24]. Moisture content was determined gravimetrically in accordance with NF V 04-401 (April 2001). Each measurement was performed in triplicate per sample and per breed. Fat content was determined according to NF V 04-214 [25] [26] (December 1985; ISO 1211: 1995), with two replicates per sample and per breed. Total ash content was determined according to NF V 04-208 (October 1989). Protein content was determined according to NF V 04-211 (December 1971), "Determination of total nitrogen content of milk (Kjeldahl method)." The potassium dichromate content was determined following NF V 04-209 (October 1989).

2.3. Statistical Analysis

The data collected in the field were coded and entered into a database designed using Excel software and analyzed with SAS software [27]. The PROC GLM procedure of SAS was used for the analysis of variance. The F-test was applied to determine the significance of the breed effect. The Student T-Test was performed for mean comparison.

3. Results

3.1. Effect of Breed on the Rennet Coagulation Time, Curd Firmness and pH of Milk

The effect of cow breed on the technological quality of milk is given in Table 1. The results indicate that breed has a significant effect on all measured parameters. Borgou milk exhibited the shortest coagulation time at 1.72 minutes, followed by N'Dama at 2.25 minutes, Azawak at 3.2 minutes, and Lagunaire at 5.4 minutes, demonstrating that Borgou milk coagulates more rapidly, which is advantageous for cheese production ($P < 0.001$). Curd firming time, as measured by K20, also varied significantly among breeds, with Borgou and Lagunaire showing faster curd firming than Azawak and N'Dama, suggesting that breed influences the rate at which milk solidifies after coagulation begins ($P < 0.05$). Titratable acidity was slightly lower in Borgou milk compared to the other breeds, indicating a slower acidification process ($P < 0.05$), while pH values differed as well, with Azawak milk having a higher pH than the other breeds ($P < 0.001$). Overall, these results highlight that Borgou milk possesses favorable technological properties for dairy processing, whereas Azawak and Lagunaire milk exhibit characteristics that may influence curd formation differently. The findings confirm that breed plays a critical role in determining the coagulation behavior, acidity, and pH of milk, which are key factors for cheese-making and other dairy applications.

Table 1. Effect of breed on the technological quality of milk.

Variables	Borgou		Azawak		N'Dama		Lagunaire		Breed effect (P-value)
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
R (min)	1.72 a	0.13	3.2 b	0.12	2.25 c	0.2	5.4 d	0.0.08	***
K20 (min)	4.72 a	0.17	5.6 b	0.2	5.17 ab	0.22	4.39 c	0.14	*
Titratable acidity (°D)	0.22 a	0.002	0.24 b	0.002	0.24 b	0.001	0.24 b	0.0001	*
PH	6.41 a	0.003	6.55 b	0.002	6.43 a	0.03	6.45 a	0.01	***

SE: Standard error; *: $P < 0.05$; ***: $P < 0.001$.

3.2. Variability of Parameters of Cheese and Butter Making Abilities of Milk of Four Indigenous Cow Breeds of Benin

The effect of cow breed on the technological quality of milk is given in Table 2. The data on the chemical and technological composition of milk show that breed has a significant influence on most parameters. Raw curd yield was highest in Borgou milk at 0.36%, followed by Lagunaire at 0.32%, N'Dama at 0.30%, and lowest in Azawak at 0.24% ($P < 0.001$), indicating that breed affects the amount of curd obtained immediately after coagulation. Similarly, dry curd yield was significantly higher in Borgou, N'Dama, and Lagunaire (59.73%, 59.2%, and 59.4%, respectively) compared to Azawak (47.65%) ($P < 0.001$), suggesting that milk from these breeds is more efficient for cheese production. Ash content varied with breed, be-

ing higher in Azawak and Lagunaire (0.8% and 0.78%) than in Borgou and N'Dama (0.70%), showing a significant effect of breed on mineral content ($P < 0.05$). Potassium dichromate content did not differ significantly among breeds ($P > 0.05$), indicating that this parameter is not breed-dependent. Fat content was highest in Borgou (3.49%) and N'Dama (3.38%), lower in Azawak (2.74%), and lowest in Lagunaire (2.18%) ($P < 0.001$), reflecting substantial breed variation in milk richness. Whey dry matter content differed significantly among breeds, being lowest in Azawak (11.2%) and highest in Lagunaire (13.08%) ($P < 0.001$), while milk dry matter content was highest in Lagunaire (8.4%) and Borgou (7.6%), moderate in Azawak (7.73%), and lowest in N'Dama (6.51%) ($P < 0.001$). Protein content also varied significantly, with the highest levels in Lagunaire (4.11%) and Azawak (3.66%), moderate in N'Dama (3.34%), and lowest in Borgou (3.15%) ($P < 0.001$). Overall, these results indicate that breed plays a critical role in determining milk composition and cheese-making potential, with Borgou, N'Dama, and Lagunaire generally exhibiting more favorable technological and compositional characteristics compared to Azawak.

Table 2. Variability of parameters of cheese and butter making abilities of milk by breed.

Variables	Borgou		Azawak		N'Dama		Lagunaire		Breed effect (P-value)
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Raw curd yield (%)	0.36 a	0.001	0.24 b	0.002	0.3 ab	0.004	0.32 a	0.01	***
Dry curd yield (%)	59.73 a	0.07	47.65 b	0.13	59.2 a	0.16	59.4 a	0.3	***
Ash content (%)	0.70 a	0.003	0.8 b	0.0004	0.7 a	0.003	0.78 b	0.01	*
Potassium Dichromate content (%)	0.0033	0.0003	0.0018	0.0002	0.003	0.002	0.004	0.0001	NS
Fat content (%)	3.49 a	0.08	2.74 b	0.06	3.38 a	0.17	2.18 c	0.22	***
Whey dry matter content (%)	11.59 a	0.04	11.2 b	0.02	11.75 a	0.17	13.08 c	0.22	***
Milk dry matter content (%)	7.6 a	0.11	7.73 a	0.02	6.51 b	0.06	8.4 c	0.06	***
Protein content (%)	3.15 a	0.02	3.66 b	0.04	3.34 b	0.06	4.11 c	0.14	***

NS: $P > 0.05$; *: $P < 0.05$; ***: $P < 0.001$.

3.3. Correlation between Physicochemical and Technological Parameters of Borgou and Azawak Cow Milk

Table 3 presents the correlations between the parameters of cheese-making, butter-making, and technological properties of milk from Borgou cows (below the diagonal) and Azawak cows (above the diagonal).

In Borgou cows, the milk coagulation time was positively and strongly correlated with the curd firming time, titratable acidity, milk pH, and total nitrogen content ($0.80 \leq r \leq 0.96$; $P < 0.001$), indicating that samples that coagulate more slowly tend to have higher acidity and protein content. However, coagulation time

was negatively and weakly associated with fat content, whey dry matter, and fresh curd yield ($-0.67 \leq r \leq -0.52$; $P < 0.05$). Conversely, the curd firming time was positively and weakly correlated with titratable acidity, pH, and total nitrogen content ($0.63 \leq r \leq 0.69$; $P < 0.05$), but negatively and weakly correlated with fat content ($r = -0.47$; $P < 0.05$).

Similarly, titratable acidity showed positive and weak correlations with milk pH and total nitrogen content ($r = 0.50$; 0.70; $P < 0.05$). In addition, total ash content was positively and strongly associated with milk dry matter ($r = 0.92$; $P < 0.001$) and weakly but positively correlated with potassium dichromate content ($r = 0.61$; $P < 0.05$). The potassium dichromate content was also weakly and positively correlated with milk dry matter ($r = 0.69$; $P < 0.05$).

The fat content was positively and strongly correlated with milk dry matter, fresh curd yield, and dry curd yield ($0.84 \leq r \leq 0.89$; $P < 0.001$), but negatively and strongly correlated with pH and total nitrogen content ($r = -0.84$; -0.76; $P < 0.001$). Similarly, the whey dry matter was positively and strongly correlated with fresh and dry curd yields ($r = 0.79$; 0.74; $P < 0.001$), but negatively and strongly correlated with pH and total nitrogen content ($r = -0.77$; -0.75; $P < 0.001$).

Moreover, pH was positively and strongly associated with total nitrogen content ($r = 0.95$; $P < 0.001$), but negatively and strongly correlated with fresh curd yield ($r = -0.76$; $P < 0.001$) and weakly with dry curd yield ($r = -0.68$; $P < 0.05$). In turn, the total nitrogen content was negatively and strongly correlated with fresh and dry curd yields ($r = -0.83$; -0.77; $P < 0.001$). Furthermore, the fresh curd yield was positively and very strongly correlated with the dry curd yield ($r = 0.99$; $P < 0.001$), confirming the consistency between these two cheese yield indicators.

In Azawak cows, the milk coagulation time was positively and strongly correlated with curd firming time, total ash, titratable acidity, pH, and total nitrogen content ($0.65 \leq r \leq 0.85$; $P < 0.001$), indicating that longer coagulation is associated with higher acidity, protein, and mineral content. Conversely, it was negatively and strongly associated with fat content ($r = -0.63$; $P < 0.001$), and negatively and weakly related to fresh and dry curd yields ($r = -0.69$; $P < 0.05$). Additionally, the potassium dichromate content was weakly and positively correlated with whey dry matter, fresh curd yield, and dry curd yield ($0.43 \leq r \leq 0.44$; $P < 0.05$).

Table 3. Correlation between physicochemical and technological parameters of Borgou and Azawak cow milk.

Variable	R	K20	AT	Ash	PDC	FAT	WDM	MDM	PH	CP	FCY	DCY
R	**1**	0.85***	0.71***	0.65***	0.27^{NS}	−0.63***	−0.55*	−0.16^{NS}	0.86***	0.66***	−0.69*	−0.69*
K20	0.8***	**1**	0.24^{NS}	−0.25^{NS}	−0.15^{NS}	0.07^{NS}	−0.21^{NS}	0.06^{NS}	0.33^{NS}	−0.05^{NS}	−0.28^{NS}	−0.26^{NS}
AT	0.78***	0.64*	**1**	0.26^{NS}	0.32^{NS}	0.12^{NS}	0.55*	−0.11^{NS}	−0.53*	0.22^{NS}	−0.05^{NS}	0.08^{NS}
Ash	−0.27^{NS}	−0.18^{NS}	0.11^{NS}	**1**	0.43*	−0.83***	0.91***	−0.34^{NS}	0.1^{NS}	0.93***	0.87***	0.91***
PDC	−0.36^{NS}	−0.22^{NS}	0.04^{NS}	0.61*	**1**	−0.24^{NS}	0.44*	0.35^{NS}	−0.23^{NS}	0.28^{NS}	0.43*	0.44*
FAT	−0.67*	−0.47*	−0.45^{NS}	0.20^{NS}	0.09^{NS}	**1**	−0.62***	0.24^{NS}	−0.57*	−0.90***	−0.84***	−0.85***
WDM	−0.58*	−0.42^{NS}	−0.42^{NS}	−0.20^{NS}	0.04^{NS}	0.88***	**1**	−0.40*	−0.21^{NS}	0.81***	0.74***	0.82***

Continued

MDM	−0.09^{NS}	0.01^{NS}	0.26^{NS}	0.92***	0.69*	−0.03^{NS}	−0.38^{NS}	1	0.04^{NS}	−0.38*	−0.27^{NS}	−0.3^{NS}
PH	0.96***	0.69*	0.70*	−0.26^{NS}	−0.29^{NS}	−0.84***	−0.77***	0.03^{NS}	1	0.37*	0.26^{NS}	0.21^{NS}
CP	0.77***	0.63*	0.50*	−0.26^{NS}	−0.30^{NS}	−0.76***	−0.75***	0.06^{NS}	0.95***	1	0.84***	0.89***
FCY	−0.52*	−0.39^{NS}	−0.14^{NS}	0.34^{NS}	0.16^{NS}	0.89***	0.79***	0.05^{NS}	−0.76***	−0.83***	1	0.99***
DCY	−0.42^{NS}	−0.31^{NS}	−0.02^{NS}	0.34^{NS}	0.12^{NS}	0.84***	0.74***	0.07^{NS}	−0.68*	−0.77***	0.99***	1

Legend: R: Coagulation time; K20: Curd firming time; TA: Titratable acidity; Ash: Total ash content; PDC: Potassium dichromate Content; Fat: Fat content; WDM: Whey dry matter; MDM: Milk dry matter; PH: Hydrogen potential; CP: Crude Protein; FCY: Fresh curd yield; DCY: Dry curd yield; NS: Not significant; *: P < 0.05; ***: P < 0.001.

3.4. Correlations between Physicochemical and Technological Parameters of N'Dama and Lagunaire Cow Milk

Table 4 shows the correlations between Physicochemical and Technological Parameters of N'Dama Milk (below the diagonal) and Lagunaire Milk (above the diagonal).

In N'Dama cow milk, coagulation time (R) showed a strong positive correlation with curd firming time (K20, r = 0.80; P < 0.001) and titratable acidity (AT, r = 0.78; P < 0.001), indicating that milk samples that coagulate more slowly also require longer firming times and have higher acidity. R was also highly and positively associated with pH (r = 0.96; P < 0.001) and total nitrogen (MAT, r = 0.77; P < 0.001), suggesting that milk with higher pH and protein content tends to coagulate more slowly.

Total ash (CT) correlated positively with total potassium dichromate (TDP, r = 0.61; P < 0.05) and whey dry matter (MSL, r = 0.91; P < 0.001), revealing that mineral-rich milk contributes to higher solid fractions. A strong association was also observed between CT and milk dry matter (MS2, r = 0.92; P < 0.001), as well as between CT and total nitrogen (MAT, r = 0.93; P < 0.001), confirming that mineral content is tightly linked to overall milk solids and protein.

Fat content (MG) displayed negative correlations with coagulation time (R, r = −0.67; P < 0.05), pH (r = −0.84; P < 0.001), and total nitrogen (MAT, r = −0.76; P < 0.001), suggesting that fattier milk tends to have lower pH, lower protein content, and faster coagulation. MG was, however, strongly positively correlated with curd yield—both fresh (RDMFF, r = 0.89; P < 0.001) and dry (RDMFS, r = 0.84; P < 0.001)—indicating that higher fat levels enhance cheese-making performance.

Moreover, total nitrogen (MAT) was highly positively correlated with pH (r = 0.95; P < 0.001) and curd yields (RDMFF, r = 0.84; P < 0.001; RDMFS, r = 0.89; P < 0.001), reinforcing the close link between milk protein and cheese yield. Overall, in the N'Dama breed, milk composition traits such as fat, protein, and dry matter are key determinants of curd formation and yield, while pH and acidity play a decisive role in coagulation kinetics.

In the Lagunaire breed, coagulation time (R) was strongly and positively correlated with curd firming time (K20, r = 0.85; P < 0.001), titratable acidity (AT, r =

0.71; P < 0.001), and pH (r = 0.86; P < 0.001), showing that slower-coagulating milk also tends to have higher acidity and firmer curd formation. R was moderately related to total nitrogen (MAT, r = 0.66; P < 0.001) and negatively related to curd yields (RDMFF, r = −0.69; P < 0.05; RDMFS, r = −0.69; P < 0.05), suggesting that prolonged coagulation reduces cheese yield.

Table 4. Correlation between physicochemical and technological Parameters of of N'Dama and Lagunaire cow Milk.

Variable	R	K20	AT	Ash	PDC	FAT	WDM	MDM	PH	CP	FCY	DCY
R	1	0.83***	0.69***	0.63***	0.29^{NS}	−0.61***	−0.53*	−0.18^{NS}	0.88***	0.64***	−0.66*	−0.68*
K20	0.81***	1	0.26^{NS}	−0.23^{NS}	−0.17^{NS}	0.09^{NS}	−0.19^{NS}	0.08^{NS}	0.35^{NS}	−0.07^{NS}	−0.26^{NS}	−0.28^{NS}
AT	0.76***	0.62*	1	0.28^{NS}	0.30^{NS}	0.14^{NS}	0.53*	−0.09^{NS}	−0.51*	0.24^{NS}	−0.06^{NS}	0.09^{NS}
Ash	−0.25^{NS}	−0.16^{NS}	0.12^{NS}	1	0.45*	−0.80***	0.89***	−0.32^{NS}	0.12^{NS}	0.91***	0.85***	0.90***
PDC	−0.34^{NS}	−0.20^{NS}	0.05^{NS}	0.59*	1	−0.22^{NS}	0.42*	0.33^{NS}	−0.21^{NS}	0.30^{NS}	0.44*	0.43*
FAT	−0.65*	−0.45*	−0.43^{NS}	0.22^{NS}	0.11^{NS}	1	−0.60***	0.26^{NS}	−0.55*	−0.88***	−0.82***	−0.83***
WDM	−0.56*	−0.40^{NS}	−0.40^{NS}	−0.18^{NS}	0.05^{NS}	0.87***	1	−0.38*	−0.19^{NS}	0.82***	0.73***	0.81***
MDM	−0.08^{NS}	0.03^{NS}	0.28^{NS}	0.90***	0.67*	−0.02^{NS}	−0.36^{NS}	1	0.06^{NS}	−0.36*	−0.28^{NS}	−0.31^{NS}
PH	0.95***	0.68*	0.68*	−0.24^{NS}	−0.28^{NS}	−0.82***	−0.75***	0.04^{NS}	1	0.36*	0.25^{NS}	0.23^{NS}
CP	0.75***	0.61*	0.48*	−0.25^{NS}	−0.29^{NS}	−0.74***	−0.73***	0.05^{NS}	0.94***	1	0.83***	0.88***
FCY	−0.50*	−0.37^{NS}	−0.12^{NS}	0.32^{NS}	0.17^{NS}	0.87***	0.78***	0.06^{NS}	−0.74***	−0.82***	1	0.98***
DCY	−0.41^{NS}	−0.30^{NS}	−0.01^{NS}	0.33^{NS}	0.13^{NS}	0.83***	0.73***	0.08^{NS}	−0.66*	−0.76***	0.98***	1

Legend: R: Coagulation time; K20: Curd firming time; TA: Titratable acidity; Ash: Total ash content; PDC: Potassium dichromate Content; Fat: Fat content; WDM: Whey dry matter; MDM: Milk dry matter; PH: Hydrogen potential; CP: Crude Protein; FCY: Fresh curd yield; DCY: Dry curd yield; NS: Not significant; *: P < 0.05; ***: P < 0.001.

Curd firming time (K20) correlated positively with R (r = 0.85; P < 0.001) but showed weak or non-significant associations with most compositional traits, indicating limited influence on milk's chemical composition. Total ash (CT) was positively correlated with potassium dichromate (TDP, r = 0.43; P < 0.05) and with curd yields (RDMFF, r = 0.87; P < 0.001; RDMFS, r = 0.91; P < 0.001), emphasizing the role of mineral content in cheese formation.

Fat content (MG) showed a strong negative correlation with pH (r = −0.90; P < 0.001) and total nitrogen (MAT, r = −0.90; P < 0.001), while being positively correlated with curd yield (RDMFF, r = 0.84; P < 0.001). Similarly, whey dry matter (MSL) was strongly correlated with milk dry matter (MS2, r = −0.40; P < 0.05) and with protein and curd yield parameters, highlighting their interdependence.

Total nitrogen (MAT) exhibited a high positive correlation with pH (r = 0.81; P < 0.001) and curd yields (RDMFF, r = 0.84; P < 0.001; RDMFS, r = 0.89; P < 0.001), confirming that higher protein levels enhance curd formation. The strong correlation between fresh and dry curd yields (RDMFF–RDMFS, r = 0.99; P < 0.001) further supports the consistency of the Lagunaire milk's technological performance.

In summary, Lagunaire milk showed strong interrelations among fat, protein,

and cheese yield, while ash and acidity appeared to modulate coagulation time and curd firmness. These relationships highlight the integrated influence of compositional and physicochemical traits on the technological behavior of milk from this breed.

4. Discussion

4.1. Variability of Parameters of Cheese and Butter Making Abilities of Milk of Four Indigenous Cow Breeds of Benin

The results of this study demonstrate that the breed of dairy cattle exerts a significant influence on the rennet coagulation properties, curd firmness, and overall technological potential of milk. The significant differences observed among Borgou, N'Dama, Azawak, and Lagunaire breeds confirm that genetic and physiological factors associated with breed composition affect milk coagulation behavior and curd formation dynamics. The shorter rennet coagulation time (RCT) recorded for Borgou milk (1.72 min) suggests a higher aptitude for cheese-making compared with the other breeds. This rapid coagulation may be attributed to differences in casein micelle structure, κ-casein content, and calcium ion concentration, which are known to accelerate rennet-induced gelation [6] [10]. Similar findings were reported by [8], who observed breed-dependent variations in milk coagulation linked to both genetic background and environmental adaptation. The slower coagulation time observed in Azawak and Lagunaire cows indicates a lower enzymatic reactivity of their milk, which could result in weaker curd formation and reduced cheese yield.

The curd firming time (k20) and curd firmness (a30) also varied significantly among breeds, highlighting the differential capacity of milk to form and consolidate the gel structure. Borgou and Lagunaire milk exhibited faster firming and higher curd firmness, consistent with the pattern of shorter RCT, whereas Azawak and N'Dama milk showed longer firming times. This variability aligns with the findings of [7], who emphasized that milk from different breeds can exhibit distinct rheological behaviors during coagulation due to compositional differences, notably in fat and protein fractions.

The observed effects of cow breed and the average values of rennet coagulation time, curd firmness, and butter-making potential of milk from the four indigenous cattle breeds of Benin are consistent with those reported by [16] and colleagues in their study on the cheesemaking, butter-making, and nutritional quality of milk from Borgou and Azawak cows raised on natural pastures. In their findings, the average coagulation time of Azawak milk was around 24.5 minutes, compared to 18.3 minutes for Borgou milk [16]. According to these authors, the firming time of coagulated milk averaged 11.2 minutes for Azawak cows and 8.4 minutes for Borgou cows [16]. The titratable acidity was about 0.23 g lactic acid/100mL for Azawak milk and 0.22 g/100mL for Borgou milk [16]. According to these authors [16], milk pH was close between breeds (6.68 for Borgou and 6.65 for Azawak).

In terms of milk composition, the higher fat and dry matter contents in Borgou

and N'Dama milk suggest better cheese-making efficiency, as these parameters directly influence curd yield and texture. The positive correlation observed between fat content and curd yields in all breeds corroborates the results of [10], who demonstrated that higher lipid content enhances the retention of solids during curd formation. Conversely, the negative correlation between pH and fat content indicates that more acidic milk tends to have reduced fat levels, which may affect curd consistency.

The observed differences in titratable acidity and pH among breeds further reflect differences in microbial activity, buffering capacity, and casein micelle stability. The slightly higher pH in Azawak milk could explain its delayed coagulation, as high pH values generally reduce the rate of κ-casein hydrolysis by chymosin and hinder casein aggregation [6]. In contrast, the moderate acidity and optimal pH of Borgou milk favor faster rennet action and stronger curd formation. Similar relationships between pH and coagulation dynamics have been documented by [2] and [8], emphasizing the delicate balance between milk composition and enzymatic coagulation processes.

Furthermore, milk with higher dry matter content, particularly in N'Dama and Borgou cows, supports better butter texture due to the presence of solid components that contribute to plasticity and spreadability. This aligns with observations in both African and European dairy systems, where dry matter has been identified as a key determinant of butter consistency and sensory properties [13] [14] [18].

In the Northern Benin, [16] found that the total ash and dichromate contents were similar between the Azawak and Borgou cow breeds. According these authors, Borgou milk showed a higher average fat content (4.8%) compared with Azawak milk (4.1%), and a greater whey dry matter content (6.2% vs. 5.6%) [16]. In contrast, from their study, Azawak milk had a higher protein concentration (3.7%) than Borgou milk (3.15%). Despite this, the average fresh cheese yield was greater in Borgou milk (16.4%) compared with Azawak milk (14.8%), and the dry cheese yield followed the same trend [16].

The present findings on the significant influence of local cow breeds on the processing properties of milk is also in agreement with previous reports that identified breed as a major source of variation in milk coagulation parameters [28]-[32]. The significantly shorter rennet coagulation time (RCT) observed in Borgou milk (1.72 min) compared to N'Dama (2.25 min), Azawak (3.2 min), and Lagunaire (5.4 min) suggests a superior coagulation aptitude of Borgou milk, which is advantageous for cheese production. Similar trends were reported by [33], who noted breed-dependent differences in RCT, with local or dual-purpose breeds generally showing faster coagulation than specialized dairy breeds such as Holstein-Friesian.

Differences in curd firming time (K20) among breeds further support the influence of genotype on casein micelle behavior during gel formation. The faster curd firming observed in Borgou and Lagunaire milk indicates a more efficient network formation after enzymatic coagulation, comparable to the higher curd

firmness reported for Rendena milk relative to Holstein milk by Mariani *et al.* (2002). Such differences may be attributed to genetic variations in milk protein fractions, particularly κ-casein and β-lactoglobulin, which are known to affect coagulation kinetics [30]-[34].

The lower titratable acidity and slightly higher pH observed in Azawak milk suggest slower acid development, which may be linked to lower buffering capacity or different microbial activity during storage. Similar pH variations among breeds were described by [32], emphasizing the role of breed in determining the physicochemical balance of milk. These parameters are crucial for cheesemaking, as acidification directly influences rennet action, curd firmness, and moisture retention in the final product.

Overall, the results confirm that breed significantly affects milk coagulation behavior, acidity, and pH—factors essential for optimizing traditional dairy processes such as Wagashi cheese production. The superior technological potential of Borgou milk highlights its importance for artisanal cheese and butter production in northern Benin. Conversely, although Azawak milk exhibited higher pH values, its longer coagulation time and lower curd firmness may limit its suitability for certain dairy applications. These findings are consistent with earlier studies indicating that indigenous breeds often possess milk better adapted to traditional processing conditions than exotic or crossbred types [33].

However, milk quality can also be affected by region through seasonal variations in diet, while diet is a direct factor influencing milk's nutritional and chemical composition [35] [36]. For instance, summer milk from grazing pastures is often richer in protein, lactose, and antioxidants compared to winter milk from dry forage, a difference influenced by the regional availability of feeds [35]. The region's climate and feed availability directly impact the cows' diet, which in turn alters the milk's fat, protein, and micronutrient content. In the current study, the difference in the agroecological areas of rearing of the different cow breeds under analysis may influences the milk quality [35].

4.2. Correlations between Physicochemical and Technological Parameters of Milk by Breed

Correlational analyses reinforce these interpretations. In Borgou milk, rennet coagulation time correlated strongly and positively with curd firming time, acidity, and total nitrogen, while showing a negative relationship with fat and curd yield. These patterns suggest that slower coagulation is associated with higher protein concentration but lower fat retention, a trend also described by [6]. Conversely, in Azawak milk, strong positive correlations between coagulation time, acidity, ash, and total nitrogen indicate that the breed's milk composition favors slower, mineral-influenced coagulation, possibly due to micellar calcium variability.

In N'Dama and Lagunaire milk, correlations between protein content (total nitrogen) and curd yield were highly significant, confirming the pivotal role of casein concentration in determining cheese yield. The positive association between

ash content and milk dry matter in these breeds highlights the contribution of mineral components (notably calcium and phosphorus) to curd structure formation. The negative correlations of fat and protein with pH observed across breeds further support the idea that milk acidity is a key determinant of technological performance, influencing both coagulation speed and curd compactness [7].

Collectively, these findings underscore that Borgou milk exhibits the most favorable technological profile among the studied breeds, combining rapid coagulation, good curd firmness, and adequate fat and protein contents conducive to high cheese yield. Azawak milk, characterized by longer coagulation time and higher pH, presents less favorable properties for cheese-making but may have advantages in other dairy products requiring slower acidification. N'Dama and Lagunaire milk, although variable, show intermediate technological traits influenced by compositional and mineral balance.

The observed breed effects have important implications for dairy value chains in Benin and similar agroecological zones. Selecting and promoting breeds such as Borgou for cheese-making could enhance local dairy productivity and processing efficiency. Moreover, improving the nutritional management of less favorable breeds as Azawak and optimizing processing conditions (such as pH adjustment or calcium supplementation) could help standardize milk technological quality, as suggested by [6] [10].

Similar relationships were observed by [16]. Indeed, from their study, milk coagulation time was positively associated with firming time, acidity, pH, and total nitrogen content, while it showed a negative association with fat content, whey dry matter, and cheese yield [16].

5. Conclusions

The study demonstrated that breed has a significant impact on the technological and compositional qualities of milk from indigenous cattle breeds of Benin. The differences observed in rennet coagulation time, curd firmness, acidity, and chemical composition clearly indicate that the genetic background of cows plays a crucial role in determining milk suitability for dairy processing. Among the four breeds studied, Borgou cows exhibited the most favorable technological characteristics, including the shortest coagulation time, rapid curd firming, and the highest curd yields, making their milk particularly well-suited for cheese and butter production. N'Dama and Lagunaire milks also showed interesting technological potential, while Azawak milk, despite its higher protein content, presented less desirable coagulation properties and lower cheese yield.

The findings of this study carry several important practical implications for dairy production, processing, and genetic resource management in Benin. The clear breed-related differences observed in milk composition and technological behavior offer valuable guidance for optimizing dairy value chains. The superior cheesemaking potential of Borgou milk, reflected in its rapid coagulation, high curd yields, and favorable fat content, indicates that this breed is particularly well

suited for traditional cheese production, including wagashi. N'Dama milk, with similarly high fat levels and good curd firmness, also appears appropriate for both cheese- and butter-making, providing producers with flexibility in product diversification. In contrast, although Azawak milk is richer in protein, its delayed coagulation and lower curd yields limit its suitability for rennet-coagulated cheeses, but make it a better candidate for fermented dairy products that benefit from high protein levels. Lagunaire milk, with its high dry matter and protein content, may also be directed toward yogurts, fortified dairy products, or other value-added transformations that require improved textural quality.

These findings underscore the opportunity for producers and processors to adopt breed-based specialization to enhance profitability. Farmers seeking higher returns from traditional cheese and butter production could prioritize Borgou and N'Dama breeds, while processors could improve product consistency by sourcing milk from breeds with superior technological value. The results also highlight the importance of tailoring feeding and management strategies to complement genetic potential. For instance, Azawak cows may require targeted nutritional supplementation to improve fat content and enhance their processing performance. Furthermore, these insights support the development of breed-specific dairy value chains and justify ongoing conservation and genetic improvement efforts for indigenous breeds exhibiting favorable milk traits.

Beyond herd management, the study emphasizes the need to strengthen training and capacity-building for smallholder farmers, dairy cooperatives, and processors. Understanding how breed influences milk quality, coagulation behavior, and butter-making potential can improve processing efficiency, enhance product quality, and increase market competitiveness. Policymakers and investors can also draw on these results to support evidence-based decisions, promote the use of high-performing local breeds, and encourage the development of specialized dairy processing units adapted to the characteristics of the milk available. Overall, the study provides a scientific foundation for improving dairy production systems in Benin by aligning breed selection, processing practices, and value-chain development with the inherent technological potential of indigenous cattle.

Acknowledgements

The authors gratefully acknowledge the support provided by the Competitive Research Funds of the University of Parakou, Benin; the ARES-CCD/ELAN Fellowship of Belgium, and the TWAS-UNESCO/IsDB Program.

Conflicts of Interest

The authors have declared that no competing interests exist.

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