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Evaluation of the chemical and microbiological quality of a cassava-based fermentate product for animal feed

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ABSTRACT. This study aimed to evaluate the chemical and microbiological quality of a fermented cassava feed, formulated with different diluents (water or whey) and with or without the addition of an inoculant (yogurt). The experimental design was a 2x2 factorial completely randomized design, totaling 4 treatments (4 replicates each), designated A (water), B (water + yogurt), C (whey), and D (whey + yogurt). Temperature, chemical, and microbiological analyses were performed. The pH values of the treatments were adequate (between 3.92 and 4.25) and did not vary significantly. Total and thermotolerant coliforms were not detected (< 1.0E + 01). Crude protein levels varied significantly among the treatments, with the lowest level observed in treatment A (2%) and the highest level in treatment D (7.95%). The lowest crude fat values were found in treatments A and C (0.89% and 1.47%, respectively), while the highest values were observed in treatments B and D (6.525% and 6.205%, respectively). Yeast and lactic acid bacteria were found in all treatments. Fermented cassava is an economically viable alternative with good chemical and microbiological quality for animal feed, especially for small-scale producers.

Keywords: Microbiological quality; Chemical composition; Animal nutrition; Whey; Alternative foods.

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Introduction

Extreme weather events resulting from climate change, such as prolonged droughts, and increased agricultural production costs following the COVID-19 pandemic have created a shortage of raw materials for animal feed (Blain et al., 2022; Fluck et al., 2023). In this context, interest in alternative, cost-effective, sustainable foods is growing.

Cassava (*Manihot esculenta* Crantz), which is rich in starch (Vidigal Filho et al., 2022), represents an important energy source for local communities (Lobo et al., 2018) and feeds more than 800 million people (Vidigal Filho, 2022). Brazil is the fifth-largest producer worldwide, with 18.49 million tons produced in 2021 (CONAB, 2022). Cassava is mainly cultivated by family farmers (Arruda et al., 2021) and is important for human and animal nutrition. Its roots concentrate starch, and its leaves contain between 17.7% and 38.1% crude protein (Latif & Müller, 2015). Despite its high nutritional value, its use is limited by rapid post-harvest deterioration (Sanchez et al., 2006).

Fresh cassava root is one of the most economical feedstuffs for animal feed (Souza et al., 2011). According to Souza et al. (2014), cassava cultivation on family farms is notable for its ease of production, rusticity, and adaptability to low-tech planting systems. Searching for alternative ways to utilize cassava can increase its shelf life and nutritional value. Fermentation is a promising strategy for improving protein quality, fiber digestibility, and the availability of vitamins and essential amino acids (Li et al., 2020; Qin et al., 2022). Silva et al. (2021) demonstrated that the inclusion of fermented cassava roots with vinasse in the starter diet for piglets is a viable alternative. Following this approach, bovine whey—a byproduct of milk coagulation—stands out due to its high nutritional value and the necessity of proper disposal because of its polluting potential (Ganju & Gogate, 2017). Silva et al. (2021) confirmed the feasibility of including whole whey in piglet diets, resulting in improved feed conversion and animal performance.

There is an urgent need for data on cassava-based foods, given the scarcity of literature on this topic. This study is justified by the lack of recent research elucidating issues related to the chemical and microbiological quality of these foods. The objective of this study was to develop a fermented product using cassava root with whey or water addition for feeding various animal categories, including adult pigs, suckling pigs, chickens, calves, and lambs. This study proposes offering a viable nutritional alternative for family farms with limited access to corn but access to cassava.

Material and methods

Experimental design

The experimental design was completely randomized in a 2x2 factorial arrangement (with two diluents: water or whey, with or without yogurt), totaling four treatments with four replicates each. The statistical model was defined as follows:

$$y_{ijk} = \mu + D_i + I_j + (D \times I)_{ij} + \varepsilon_{ijk}$$

where yijk = is the variable analyzed in which the cassava was diluted (D) with water or whey, with or without the addition of yogurt inoculant (I), in replicate (k); m = is the overall mean; Di = is the effect of diluent i, i = 1 (Water), 2 (Whey); Ij = is the effect of yogurt inoculant j, i = 1 (Without), 2 (With); εijk = is the error associated with observation yijk, whose variation is not explained (experimental error or residual).

Data analysis

Data were analyzed using RStudio software (R Core Team, 2022). Tukey's test was performed at a 5% significance level.

Development of the cassava-based fermented product

Cassava (10 kg) was purchased from the Rio Grande do Sul Supply Center (CEASA). It was washed with running water to remove dirt and then grated with the peel using a kitchen grater. To each bucket with a 10-liter capacity, we added 1 kg of grated cassava root, 1.25 L of liquid (either whey or water), and the addition or not of commercial natural yogurt (500 g). The volume of liquid to be used was determined by the following criterion: a layer of liquid approximately 20 cm deep between the cassava and the air.

First, the cassava and whey or water were added to the buckets, followed by the yogurt, depending on the treatment. The mixture was then homogenized, and the buckets were sealed. Throughout the experiment, the ambient temperature was measured twice daily, at 7:00 a.m. and 7:00 p.m.

Treatments

The following treatments were tested: treatment A (1.25 L of water, 1 kg of cassava), treatment B (1.25 L of water, 1 kg of cassava, 500 g of yogurt), treatment C (1.25 L of whey, 1 kg of cassava) and treatment D (1.25 L of whey, 1 kg of cassava and 500 g of yogurt). Each treatment had four replicates, resulting in a total of 16 buckets. Inoculating some buckets with yogurt aimed to evaluate the fermentation capacity of cassava and indicate the influence of the diluent on this process.

Sample collection and storage

The buckets remained closed and sealed until they were opened on experimental day 21. Then, the pH and temperature were measured, and samples were collected from each bucket for microbiological and chemical analyses. Samples intended for microbiological analysis were stored in refrigerated Falcon tubes and sent to the Microbiology and One Health Laboratory, located in the Department of Microbiology, Immunology, and Parasitology at the Institute of Basic Health Sciences of the Federal University of Rio Grande do Sul. The samples for chemical analysis were stored in Ziploc bags and frozen for later analysis.

Physical and chemical evaluations

On the 21st day of the experiment, when the fermented cassava buckets were opened, the pH and temperature of the fermented cassava samples were measured using a pH meter and a thermocouple, respectively. These measurements were taken for all four treatments and all 16 replicates (four per treatment).

Partial dry matter determination

To determine the partial dry matter content at 60°C, the samples were sent to the Animal Science Laboratory (Lezo) at the Federal University of Rio Grande do Sul to be dried. The samples were completely thawed 24 hours after being removed from the freezer. Then, the samples were weighed and placed in aluminum containers for drying and subsequent dry matter (DM) assessment. The samples from all replicate treatments were divided into two aliquots (designated 1 and 2). They were kept in a forced-air oven at 60°C for 72 hours (until constant weight) and then weighed again. Partial dry matter determination at 60°C was performed as follows:

$$\text{DM } 60°\text{C} = \frac{(\text{dry sample weight} - \text{container weight}) \times 100}{\text{wet sample weight} - \text{container weight}}$$

where: DM 60ºC: Dry Matter at 60ºC

Chemical composition evaluation

After thawing and determining the dry matter at 60°C, the samples were ground in a Willey mill with a 2-mm sieve. Then, they were stored in plastic bags and transported to the Animal Nutrition Laboratory at the Federal University of Rio Grande do Sul for chemical analysis. Analyses were performed according to Association of Official Analytical Chemists [AOAC] methods for dry matter (DM) (method 930.15; AOAC, 2012). Analyses of crude protein (CP) (method 968.06; AOAC, 2012), ether extract (EE) (method 954.05; AOAC, 2012), and mineral matter (MM) (method 942.05; AOAC, 2012) were based on DM. The neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were determined using the Van Soest et al. (1991) method.

Microbiological analysis

Aliquots of 25 g of each cassava fermentation treatment were weighed aseptically and homogenized with 225 mL of 0.1% peptone water using a stomacher (Seward 400) at low intensity for 60 seconds. Decimal dilutions ranging from 10^{-1} to 10^{-5} were prepared in tubes containing 9.0 mL of sterile 0.1% peptone water. Aliquots of each of these dilutions were used for microbiological analyses. To count heterotrophic mesophilic bacteria, 0.1 mL of each dilution was inoculated into Standard Plate Count Agar. The plates were then incubated at 36 ± 1°C for 48 hours.

To determine lactic acid bacteria, 0.1 mL of each dilution was inoculated into Mann Rogosa & Sharpe (MRS) agar. The plates were incubated aerobically and anaerobically (ANAEROBAC) at 36 ± 1°C for 4 days.

To count coagulase-positive *Staphylococcus*, 0.1 mL aliquots of the dilutions were plated in triplicate on Baird-Parker agar (Acumedia, Lansing, MI, USA). The plates were incubated at 36 ± 1°C for 48 hours. Colonies displaying typical or atypical characteristics of *Staphylococcus* spp. were counted and identified. Approximately three to five typical colonies were evaluated for confirmation.

To count total and thermotolerant coliforms, 1 mL of each dilution was added to previously molten violet red bile agar (VRBA) plates, which were then maintained at 46–48°C in a water bath. After the medium solidified, an additional 15 mL of VRBA was added to each plate to form a second layer of medium. The plates were then incubated at 36 ± 1°C for 24 hours to allow for the subsequent counting of typical and atypical colonies. Typical colonies were confirmed by EC broth for thermotolerant coliforms. Mold and yeast counts were performed by inoculating 0.1 mL of the dilutions into potato dextrose agar plates. The plates were then incubated aerobically at 28°C for seven days. All counts were expressed in colony-forming units per milliliter (CFU mL^{-1}) (Ministério da Agricultura, Pecuária e Abastecimento, 2018).

Results and discussion

The environmental temperature measurements obtained during the 21-day experimental period yielded an average temperature of 15.48°C, with a standard deviation of 2.86. The environmental temperature at the time the buckets were opened was 16.6°C. Temperature is a critical parameter in the context of quality control in food production. Among the extrinsic factors that affect microbial growth are relative humidity and environmental temperature. A reduction in storage temperature has been demonstrated to be associated with a decrease in the speed of chemical reactions, enzymatic activity, and microbial multiplication, thereby prolonging the shelf life of products (Oliveira, 2020). The measurement of temperature was also intended to provide a contextual framework for understanding the storage conditions of fermented cassava products, given the paucity of available information on this subject.

The mean temperatures of the treatment replicates were 17.35°C (treatment A), 17.45°C (treatment B), 17.30°C (treatment C), and 17.17°C (treatment D). The mean pH values obtained from the replicates were 4.25 (treatment A), 4.12 (treatment B), 3.92 (treatment C), and 4.00 (treatment D).

The pH values did not vary statistically between treatments according to analysis of variance (ANOVA). The pH values are in accordance with the value recommended by Fagberno and Jauncey (1988) of less than 4.5, characterizing acidification by microorganisms. The production of antimicrobial compounds such as lactic acid by microorganisms during fermentation results in a drop in pH and inhibition of pathogenic microorganisms (Adesulu-Dahunsi et al., 2022). Reis et al. (2010) recommended pH values of 4.0 to 4.5 for fermented dairy products. By lowering the pH to values below 4.5, favorable microbiological processes can be maintained and the development of undesirable bacteria can be prevented (Hoyo et al., 2006). The analysis of variance (ANOVA) revealed that temperature values did not vary significantly between treatments, maintaining proximity to the mean values of each group. The coefficient of variation for pH was 0.03%, while for temperature, it was 0.95%. The *p*-values for pH and temperature were 0.1769 and 0.1809, respectively. Temperature is a critical parameter in the quality control of fermented products, especially after the fermentation process is complete. Increases in temperature during this stage can promote the proliferation of undesirable microorganisms, leading to chemical alterations and potential risks of spoilage or food poisoning (Moonga et al., 2021). There are no references regarding the optimal temperature for the fermented product developed in this study. The results of the microbiological analyses conducted indicate that the product is microbiologically safe at a mean post-fermentation temperature of 17.35°C.

After the samples reached a constant weight in the forced air oven at 60°C, the mean partial dry matter was as follows: 15.97% for Treatment A, 13.12% for Treatment B, 16.42% for Treatment C, and 16.95% for Treatment D. Treatment D had the highest partial dry matter content at 60°C, probably because the formulation included yogurt and whey.

The treatments were significantly different according to the F-test at the 5% level. Breaking down the factorial (2 x 2), the inoculant effect was not significant ($p > 0.05$). However, the difference in diluent (water vs. whey) was significant when statistically compared ($p < 0.0521$) by Tukey's test. Thus, the difference in dry matter of the fermented cassava samples diluted with water or whey after 21 days of fermentation at 60°C is shown. The whey diluent resulted in a higher partial dry matter content than the water diluent because whey has a dry matter content of 6.00% (Schroeder et al., 2017), whereas water does not contribute to dry matter content.

The mean values of the chemical analyses according to the treatments are listed in Table 1. Noteworthy differences were found in crude protein between treatments A (2.0%) and D (7.95%), as well as in fat values: lower for treatments A and C (0.89% and 1.47%, respectively) than for treatments B and D (6.525 and 6.205%, respectively).

Table 1. Mean values of the chemical composition of the fermented cassava per treatment.

Treatment	DM (%)	Moisture (%)	AS (%)	CP (%)	F (%)	NDF (%)	ADF (%)
A	12.70	87.30	2.72	2.00	0.89	3.43	2.73
B	11.62	88.37	3.34	6.20	6.52	2.53	2.15
C	14.25	85.75	4.40	4.65	1.47	2.87	2.05
D	14.815	85.18	4.30	7.95	6.20	3.45	2.08

Treatment A: 1.25 L of water, 1 kg of cassava; Treatment B: 1.25 L of water, 1 kg of cassava, 500 g of yogurt; Treatment C: 1.25 L of whey, 1 kg of cassava; Treatment D: 1.25 L of whey, 1 kg of cassava, 500 g of yogurt. DM – Dry matter; AS - Ashes; CP – Crude protein; F – Fat; NDF – Neutral detergent fiber; ADF – Acid detergent fiber.

Table 2 presents the mean values of the chemical composition of the different cassava fermentation treatments, relating the diluent (water or whey) and inoculant (with or without yogurt) variables. Table 3 lists the statistical significance values. Considering a 5% significance level, the mean crude protein varied significantly among all treatments, and the mean crude fat values were higher for the treatments containing yogurt. Crude protein values were higher for the treatments with whey and those with yogurt, with no significant differences between these two. The increase in crude protein values observed in these treatments can be explained by the nutritional properties of these substances, which act as diluents and additional sources of high-biological-value proteins. Whey, a by-product of milk coagulation, contains approximately 55% of its original nutrients, including soluble proteins such as β-lactoglobulin, α-lactalbumin, bovine serum albumin, and immunoglobulins (Alves et al., 2014). The increase in crude protein values in yogurt-inoculated treatments can be attributed to the protein composition and fermentation activity of microorganisms present in the product, such as *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. These microorganisms act in protein hydrolysis and bioactive peptide synthesis during fermentation (Hadjimbei et al., 2022).

Means followed by different letters, in the same row, are statistically different ($p < 0.05$) by Tukey's test.

Due to the limited literature on the chemical analysis of fermented cassava products, it is difficult to compare our results with those of other studies.

Table 2. Mean results of the chemical composition of the fermented cassava product as a function of the variables Diluent (water or whey) and Inoculant (with or without Yogurt).

Variables	Diluent		Inoculant	
	Water	Whey	Without yogurt	With yogurt
DM (%)	12,0871 b	14,1587 a	13,1600	13,2200
Moisture (%)	87,9123 a	85,4663 b	86,7800	86,4114
AS (%)	3,0757 b	4,3437 a	3,6814	3,8138
CP (%)	4,3457 b	6,2987 a	3,5129 b	7,0275 a
F (%)	4,1115	3,8363	1,2214 b	6,3650 a

DM – Dry matter, AS - Ashes; CP – Crude protein, F – Fat.

Table 3. *p*-value of the variables dilution and inoculant.

	p-value Dilution (Dil)	*p*-value Inoculant (Inoc)	*p*-value Dil x Inoc
DM	0.00690	0.74510	0.08380
Moisture	0.00118	0.73702	0.17601
AS	0.00002	0.22080	0.05890
CP	0.01026	0.00010	0.54590
F	0.46858	0.00000	0.25054

DM – Dry matter, AS - Ashes; CP – Crude protein, F – Fat.

Table 3 presents the *p*-values for the dilution and inoculant variables, as well as the *p*-value for the dilution-inoculant interaction. At a 5% significance level, the dilution treatments resulted in significant differences for dry matter (DM), moisture, ash (AS), and crude protein (CP). The inoculant variable demonstrated significant differences for CP and F. The interaction between the two variables did not cause a statistical difference for the analyzed variables. The statistical difference for the inoculant variable can be explained by the presence of fatty acids, such as linoleic acid (ω-6), linolenic acid (ω-3), and conjugated linoleic acid (CLA), in yogurt (Milani et al., 2016).

The inoculant variable demonstrated statistical differences for DM, moisture, and AS. The interaction between the two variables demonstrated statistical differences for DM, moisture, AS, CP, and F.

When analyzing the neutral detergent fiber of the fermented cassava product, an interaction effect between dilution and inoculant was observed, which was significant at $p < 0.0299$. Table 4 shows that treatments inoculated with yogurt had a higher average NDF for the whey diluent (3.4575%) than the fermented product diluted in water (2.5350%).

Table 4. Mean values of acid detergent fiber (ADF, %) of fermented cassava product diluted with water or whey, with or without yogurt inoculant.

	Inoculant	Diluent (%)	
		Water	Whey
ADF	Without yogurt	2,7333aA	2,0525aB
	With yogurt	2,1550aB	2,0825aA
NDF	Without yogurt	3,3433	2,8650
	With yogurt	2,5350 b	3,4575 a

Regarding acid detergent fiber (ADF), an interaction effect between dilution and inoculant was observed, significant at $p < 0.0212$. The fermented cassava product prepared without yogurt had a higher mean ADF for the water diluent (2.7333%) than the fermented product without yogurt for the whey diluent (2.0525%). Considering the ADF of the fermented product with yogurt added, no statistical difference was detected between the diluents, with a mean value of 2.1188%. However, a significant difference was found when analyzing the fermented product diluted with water ($p < 0.0051$). The fermented product without yogurt had a higher ADF content than the product with yogurt. However, this difference was not observed when the product was prepared with whey ($p < 0.8489$), where the mean ADF content was 2.0675% for treatments with and without yogurt. These results suggest that the addition of inoculant and whey to the fermented product may lead to a greater breakdown of ADF, making the food more digestible with a lower ADF content.

Mean values followed by different lowercase letters, in the same row, are significantly different ($p < 0.05$) for the effect of diluent, and mean values followed by different uppercase letters, in the same column, are significantly different ($p < 0.05$) for the effect of inoculant by Tukey's test.

The fermented products exhibited low levels of NDF and ADF. According to Silva et al. (2012), cassava roots have an NDF content of 6.88% and an ADF content of 4.62%. The same authors state that cassava has low physically effective fiber because it is not considered a bulky feed. It can be compared to corn, which had an NDF content of 11.76% in the same study.

The fermented product developed in this study was made with cassava roots, which are known for their high starch content, and was subjected to two treatments with whey, a high-nutritional-value byproduct. While the results are promising, further studies are needed to evaluate its use in the diet for different categories of animals. For example, in calves, diets rich in starch positively influence microbial colonization and rumen development (Khan et al., 2016). Early introduction of solid foods promotes the growth of rumen papillae and facilitates transition from liquid to solid diets, leading to better nutritional utilization and post-weaning performance (Medina et al., 2021; Simeone & Beretta, 2016).

Table 5 details the mean count of microorganisms in the fermented products. The absence of total or thermotolerant coliform colony-forming units demonstrates the product's safety and sanitary quality, as ANVISA Resolution No. 12 establishes a maximum limit of 10 CFU mL^{-1} for *E. coli* in fermented milks and other foods. Samples with counts higher than this limit are considered unfit for consumption due to possible fecal contamination (Ministério da Saúde, 2001).

Table 5. Mean count of microorganisms analyzed (CFU mL^{-1}) in different treatments tested.

Treatment	Coagulase-positive *Staphylococcus*	Total and thermotolerant coliforms (15–150 colonies)	Lactic acid bacteria	Molds (15–150 colonies)	Yeasts (15–150 colonies)
A	1.19E + 07	< 1.0E + 01	Countless	< 8.88E + 03	1.50E + 08
B	5.67E + 06	< 1.0E + 01	Countless	<1.5E + 03	1.56E + 08
C	1.27E + 06	< 1.0E + 01	2.11E + 08	<1.5E + 03	7.00E + 07
D	2.67E + 05	< 1.0E + 01	1.03E + 08	<1.5E + 03	9.58E + 07

Treatment A: 1.25 L of water, 1 kg of cassava; Treatment B: 1.25 L of water, 1 kg of cassava, 500 g of yogurt; Treatment C: 1.25 L of whey, 1 kg of cassava; Treatment D: 1.25 L of whey, 1 kg of cassava, 500 g of yogurt.

Treatments A and B contained countless colony-forming units of lactic acid bacteria per mL. According to Miambi et al. (2003), the bacteria involved in cassava fermentation are *Lactobacillus*, *Pediococcus*, *Clostridium*, *Propionibacterium*, and *Bacillus* spp. Lactic acid bacteria are known to predominate in cassava fermentation (Emmanuel et al., 2015). Orozco et al. (2018) analyzed the *Lactobacillus* species present in fermented cassava samples and identified two different species: *L. casei* and *L. brevis*. Oyewole & Odunfa (1990) indicated that yeast is one of the predominant microorganisms at the end of cassava fermentation, a finding that was also evidenced in the present study. Furthermore, yeasts are important for the survival of lactic acid bacteria during cassava fermentation because they transform cassava starch into simple sugars through their amylolytic activity. These simple sugars are then available to lactic acid bacteria, which transform them into organic acids (Oyewole, 2001).

One of the most significant challenges for newborn animals in dairy production systems is diarrhea. A survey in the United States and Canada found that 23% of calves on dairy farms are treated with antibiotics for diarrhea (Windeyer et al., 2014). Developing a commensal microbiota in the gastrointestinal epithelium is crucial for preventing infections, strengthening intestinal barrier function, and consequently improving production efficiency, food safety, and animal welfare (Steele et al., 2016). Increased *Lactobacillus* counts favor colonization by beneficial bacteria, especially in newborn ruminants, whose microbiota is still developing. In this context, fermented foods can contribute to rumen development if they contain ingredients that stimulate microbial activity and establishment (Abubackr et al., 2014).

Yeast counts differed according to the different diluents tested ($p = 0.0113$). Fermented cassava products diluted in water had higher yeast counts, as shown in Table 6.

When analyzing lactic acid bacteria, treatments with water, both with and without yogurt, resulted in an infinite number of CFU mL-1. However, the treatments with whey, with and without yogurt, showed a significant difference ($p = 0.02194$). The treatment without yogurt resulted in greater lactic acid bacterial proliferation than the treatment with yogurt, with values of 2.11E + 08 and 1.03E + 08, respectively. Table 7 shows the p-values of the dilution and inoculant variables for CFU mL-1. These results indicate that yeast counts were significantly affected by the diluent (p = 0.01126).

Table 6. Mean count of microorganisms in the different treatments.

Variables	Diluent		Inoculant	
	Water	Whey	Without yogurt	With yogurt
Mesophilic Bacteria (CFU mL^{-1})	2.43E + 08	2.16E + 08	2.16E + 08	2.39E + 08
Staphylococcus (CFU mL^{-1})	6.27E + 07	5.06E + 07	6.09E + 07	5.22E + 07
Total and thermotolerant coliforms (CFU mL^{-1})	1.00E + 01	1.00E + 01	1.00E + 01	1.00E + 01
Molds (CFU mL^{-1})	1.50E + 03	1.50E + 03	1.50E + 03	1.50E + 03
Yeasts (CFU mL^{-1})	1.51E + 08a	9.3E + 07b	1.15E + 08	1.24E + 08

Table 7. *p*-value of the dilution and inoculant variables for colony-forming units mL^{-1}. ~~(não citada no corpo do texto)~~

Variables	*p*-value Dilution (Dil)	*p*-value Inoculant (Inoc)	*p*-value Dil x Inoc
Mesophilic Bacteria	0.22402	0.32154	0.82789
Staphylococcus	0.81958	0.85816	0.85880
Total and Thermotolerant Coliforms	0.28607	0.25372	0.21989
Molds	0.28607	0.25372	0.21989
Yeasts	0.01126	0.80230	0.96470

Conclusion

The developed fermented product has chemical and microbiological characteristics that are suitable for potential use in animal feed. The pH values and the absence of coliforms indicate safety. The higher crude protein and fat content in the whey and yogurt treatments highlights their relevance as nutritional sources. The presence of lactic acid bacteria and yeast further supports the product's functional and probiotic potential. In conclusion, the product is economically viable, of satisfactory quality, and represents a promising alternative for small-scale producers. However, further studies are required to evaluate its digestibility in different animal categories.

Data availability

All data generated or analyzed during this study are included in this published article.

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