biology and life sciences forum

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Proceeding Paper

Utilizing Near-Infrared Spectroscopy for Discriminant Analysis of Goat Milk Composition across Diverse Breeds and Lactation Seasons

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† Presented at the 4th International Electronic Conference on Foods, 15–30 October 2023; Available online: https://foods2023.sciforum.net/.

Abstract: Goat milk is a vital, sustainable dairy product source that contributes significantly to the global dairy market. Different goat breeds may produce milk with varying compositions during different lactation seasons. Therefore, milk composition and quality need to be monitored. As a versatile and non-destructive method, Near Infrared Spectroscopy (NIRS) offers the potential for evaluating various milk parameters. In this study, we aim to establish NIRS models for classifying goat's milk samples between the native Red and Alpine Breed at first and fifth lactation season. Our objective is to assess the efficacy and cost-effectiveness of NIRS as a viable alternative to traditional laboratory techniques. Forty-five milk samples were collected from two breeds, French Alpine goats, and native Red goats. Within each breed, half of the samples originated from goats in their first lactation season and the other half from goats in their fifth lactation season. The NIRS measurements were conducted using homogenized, untreated, and diluted milk samples. The experiment was performed with a benchtop spectrophotometer (740–1700 nm). Qualitative analysis using linear discriminant analysis (LDA) was conducted, demonstrating the feasibility of NIRS in effectively classifying samples. The achieved accuracy ranged between 67.19% to 100%, depending on the breed and lactation period. These findings underscore the potential of NIRS as a rapid, non-destructive analytical tool for quality monitoring and milk analysis. Its insights guide decision-making in nutrition, agriculture, food production, and public health. By exploiting on the distinct attributes of goat milk originating from various breeds at different lactation periods, we can offer a wide range of appropriate and varied food choices tailored to distinct population groups.

Keywords: goat milk; milk composition; Alpine and Red Breeds; NIRS models; qualitative analysis; benchtop spectrophotometer

Citation: Visoka, Y.; Majadi, M.; Kovacs, Z.; Gecaj, R.M. Utilizing Near-Infrared Spectroscopy for Discriminant Analysis of Goat Milk Composition across Diverse Breeds and Lactation Seasons. *Biol. Life Sci. Forum* **2023**, *26*, x. https://doi.org/10.3390/xxxxx

Academic Editor(s): Name

Published: date

1. Introduction

Goat's milk is a valuable dairy product that exerts a significant nutritional impact globally [1]. During 1969–2010, global trends in the evolution of the goat population and their products demonstrated a steady and rapid increase compared to cattle or sheep, particularly in developing countries [2].

Compared to cow or plant-based alternatives, goat milk offers a creamier and thicker texture and richer nutrient content [3]. Regarding elemental composition, goat milk is quite similar to cow milk, with typical percentages of 12.2% total solids, 3.8% fat, 3.5% protein, 4.1% lactose, and 0.8% ash. It has more fat, protein, and ash than cow milk but less lactose. In addition, goat milk has slightly less total casein and more nonprotein nitrogen than cow milk [21]. Goat milk contains more calcium, phosphorus, potassium, magnesium, and chlorine, while having lower levels of sodium and sulfur compared to cow's milk. Also, it contains higher levels of vitamin A [21,22]. Its complexity arises from diverse factors like breed characteristics, age, diet, as well as the lactation stage, farming method, physical environment, and seasons affecting the milk's color, flavor, and composition and enabling the creation of a variety of milk products [4].

The physiological and biochemical facts of goat milk's unique qualities are just barely known and little exploited, particularly the high levels of short and medium-chain fatty acids in goat milk, which have recognized medical values for many disorders and human diseases [5].

Studies show that kinetics of protein digestion of goat-based infant formulas are more comparable to that of human milk than of cow-based infant formula, suggesting fewer allergic reactions than cow milk [15]. Research indicates that approximately 25% of infants with cow milk allergies may also be sensitive to goat milk. Furthermore, goat milk might have a beneficial impact on heart health by reducing cholesterol levels in both the gallbladder and arteries [3,13]. Further, it has been shown that different goat breeds may produce milk with varying compositions and physicochemical parameters during different lactation seasons [16].

Traditional methods for assessing food quality (flavor, composition, contamination) are time-consuming and expensive [6].

Over the years, the dairy industry has embraced rapid analytical methods to address delays linked to traditional wet chemistry approaches in product assessment [7].

Near-Infrared Spectroscopy (NIRS) has a crucial role in the analysis and process control of dairy products, offering flexibility in assessing crucial components like total solids [7], protein, moisture, fat, lactose, urea, somatic cells, and fatty acid across various dairy products [8]. NIRS has numerous qualities that place it among the top food analysis techniques, among others, the option of online analysis that eliminates the requirement for batch sampling and reduces sampling error by averaging almost instantaneous, continuous measurements [9]. It is a physically non-destructive technology, accurate, simple to perform, objective, and can provide quantitative and qualitative results in various component analyses [7].

An essential attribute of the above assessment methods is their chemical-free nature, significantly reducing or eliminating sample preparation time [10] and making this technique environmentally friendly [11].

Another significant advantage of NIRS is the nonconsumption of the sample, allowing it to be examined again using the same or a different approach. [12]

As NIRS plays a pivotal role in the compositional analysis and quality control of dairy products and considering the nutritional benefits of goat milk, our study aims to evaluate the effectiveness and cost-efficiency of NIRS as a feasible replacement for conventional laboratory methods in goat milk samples of different breeds and lactation seasons. Given the limited research on goat milk in general and particularly in Kosovo, our primary objective is to establish NIRS models for classifying goat's milk samples between the native Red and Alpine Breeds at the first and fifth lactation seasons. We seek to ascertain whether significant differences exist between these breeds during various lactation seasons.

2. Materials and Methods

During May and July 2021, a study was conducted involving the collection of goat milk specimens from a farm near Pristina, as previously described by Gecaj et al. 2021 [16]. A total of 44 samples were meticulously gathered, comprising 20 samples derived from the French Alpine goat breed and 24 originating from the native Red breed. Half of the goat population under study were in the first season of lactation, while the remaining half were in the fifth season of lactation. Stringent sample collection protocols were adhered to, and the samples were preserved in ISO 250 mL bottles and maintained at low temperatures during transportation at the Department of Measurements and Process Control, Institute of Food Science and Technology (MATE, Budapest, HUN). Sodium Azide, a highly water-soluble bacteriostatic preservative sanctioned for milk samples, was employed to ensure sample preservation. The samples were stored at −2 °C until they were ready for analysis.

All collected milk samples were employed to obtain Near-Infrared (NIR) spectral signatures. Initially, experiments were conducted using untreated milk. Then, in order to achieve uniformity within the milk samples, a syringe-based homogenization technique was employed. This was accomplished by carefully extracting a representative portion of each milk sample with a sterile syringe. Subsequently, the milk was gently expelled back into another bottle, ensuring repeated cycles to facilitate thorough mixing and homogenization. Afterwards, experiments were performed using ten times diluted milk with distilled water. Diffuse transmittance spectra of the untreated, homogenized, and diluted milk samples were recorded using a Benchtop MetriNIR spectrometer in the wavelength range of 740–1700 nm with a spectral step of 2 nm. The spectral acquisition was performed at 25 °C with a temperature-controlled cuvette, with a sample layer thickness of 0.5 mm [17,18]. Samples were scanned in a random order, recording three consecutive scans for each of the samples [17]. The spectral acquisition occurred at room temperature, and a Voltcraft DL-121TH multi-data logger was employed to monitor any drift in the measurements due to ambient conditions. The resulting spectra were subjected to the following pretreatments: Savitzky-Golay smoothing (S-Golay) and Multiplicative scatter correction (MSC) [17].

Multivariate data analysis was conducted using the R-project software, specifically employing the aquap2 package [20]. After the inspection of the raw and pretreated spectra, exploratory data evaluation was performed with Principal Component Analysis (PCA), and classification models were built using PCA based Linear Discriminant Analysis (LDA) for the classification of the different breeds in different lactation periods [18]. Initially, we focused solely on the classification of the breeds in the first lactation period, and subsequently, we repeated the analysis exclusively for the fifth lactation period.

The models were validated using the leave one group out cross-validation method, considering two breeds in two different lactation seasons and three clusters within each period (treated, not treated, and diluted samples). This validation method assessed our model's performance in classifying milk samples between Red and Alpine breeds.

3. Results and Discussions

Analysis of the classification results of goat milk samples derived from the native Red and French Alpine breeds in their first and fifth lactation season revealed significant distinctions in chemical composition.

In the first lactation season, the Linear Discriminant Analysis (LDA) model exhibited favorable performance when classifying milk samples. Training accuracy for untreated milk samples reached 96.10% of correct classification accuracy and 74.46% of the average prediction accuracy of cross-validation (Table 1). The model built for classifying the homogenized milk samples displayed an average recognition accuracy of 95.34% and an average prediction accuracy of 73.59% during the cross-validation (Table 2). Conversely, diluted milk yielded less favorable results, recording average recognition and prediction accuracies of 93.51% and 55.56%, respectively (Table 3).

Table 1. Classification results for untreated goat milk samples for the classification of native Red breed and Alpine breed in their first lactation season.

		Alpine 1st Lactation Season	Native Red 1st Lactation Season
Acurracy Training 96.10%	**Alpine**	95.24%	3.03%
	Native Red	4.76%	96.97%
Acurracy Validation 74.46%	**Alpine**	76.19%	27.27%
	Native Red	23.81%	72.73%

Table 2. Classification results for homogenized goat milk samples for the classification of native Red breed and Alpine breed in their first lactation season.

		Alpine 1st Lactation Season	Native Red 1st Lactation Season
Acurracy Training 95.34%	**Alpine**	95.24%	4.55%
	Native Red	4.76%	95.45%
Acurracy Validation 73.59%	**Alpine**	71.43%	24.24%
	Native Red	28.57%	75.76%

Table 3. Classification results for diluted goat milk samples for the classification of native Red breed and Alpine breed in their first lactation season.

		Alpine 1st lactation Season	Native Red 1st Lactation Season
Acurracy Training 93.51%	**Alpine**	94.44%	7.41%
	Native Red	5.56%	92.59%
Acurracy Validation 55.56%	**Alpine**	55.56%	44.44%
	Native Red	44.44%	55.56%

The classification of the breeds resulted in even better accuracies using the milk samples from the fifth lactation season, with training accuracy for untreated milk at 100% and cross-validation accuracy of 80% (Table 4), and homogenized milk exhibiting average training accuracy of 100% and cross-validation accuracy of 73.61% (Table 5). While slightly less accurate, diluted milk still demonstrated respectable performance, with average training and cross-validation accuracies of 99.07% and 67.19%, respectively (Table 6).

Table 4. Classification results for untreated goat milk samples for the classification of native Red breed and Alpine breed in their fifth lactation season.

		Alpine 5th Lactation Season	Native Red 5th Lactation Season
Acurracy Training 100%	**Alpine**	100%	0%
	Native Red	0%	100%
Acurracy Validation 80%	**Alpine**	83.33%	23.33
	Native Red	16.67%	76.67%

Table 5. Classification results for homogenized goat milk samples for the classification of native Red breed and Alpine breed in their fifth lactation season.

		Alpine 5th Lactation Season	Native Red 5th Lactation Season
Acurracy Training 100%	**Alpine**	100%	0%
	Native Red	0%	100%
Acurracy Validation 73.61%	**Alpine**	91.67%	44.44%
	Native Red	8.33%	55.56%

Table 6. Classification results for diluted goat milk samples for the classification of native Red breed and Alpine breed in their fifth lactation season.

		Alpine 5th Lactation Season	Native Red 5th Lactation Season
Acurracy Training 99.07%	**Alpine**	100%	1.85%
	Native Red	0%	98.15%
Acurracy Validation 67.19%	**Alpine**	71.43%	37.04%
	Native Red	28.57%	62.96%

These results indicate that within the context of this sample set, it was possible to achieve satisfactory classification accuracy, particularly in the case of homogenized and untreated milk, through the employment of Near-Infrared Spectroscopy (NIRS).

Also, these findings underscore the importance of recognizing and understanding the compositional differences between native Red and French Alpine breeds in different lactation periods. Such knowledge is significant for detecting adulteration of different dairy products [19], optimizing nutritional quality, aligning with consumer preferences, and tailoring milk products for specific dietary and health needs. Furthermore, this discernment serves as a pivotal determinant in guiding breeding and husbandry methodologies, thus facilitating the production of goat milk and its derivatives tailored to a multifaceted array of markets and economic prospects.

Prior studies have demonstrated that NIR spectroscopy effectively classifies different liquid milk brands by utilizing principal component analysis (PCA) for visual differentiation [23]. Spectrometric instruments were also used to detect milk adulteration based on its geographical origin where PCA was employed to identify distinct milk source clusters [24]. Other studies shows that the season, lactation stage, and specific herds contributed significantly to the variations in fatty acid composition [14,16]. Near-infrared spectroscopy excels at predicting milk fat and protein content and adequately predicts lactose content [25]. Also, NIR spectroscopy, in both reflectance (for oven-dried milk) and transflectance (for liquid milk), shows promising results for predicting milk fatty acid profiles and fat categories in individual goat milk samples [26].

Various methods which have been used to analyze cow's milk from different breeds, reveal that a cow's breed has a stronger influence on macro minerals and some essential microminerals than factors like herd productivity, parity, or lactation stage [27].

Milk's solid non-fat (SNF) content decreases as cows age within a lactation period, showing an initial high, second-month low, and subsequent increase [28].

Fatty acid composition in mare milk from three breeds (early, mid, and late lactation) was analyzed using gas chromatography, considering both lactation stage and breed [29]. Some studies have not observed significant differences in milk samples from different breeds. An analysis of milk from six Austrian dairy goat breeds over eight months, using mostly traditional methods, showed significant seasonal variations but minimal statistical differences in most parameters, notably in total solids, crude protein, and fat content, which decreased from March, reached a low point between June and August, and peaked in October at the end of lactation [30].

Consistent with prior research, our study seeks to conduct a more comprehensive investigation, examining the influence of goat breeds and lactation stages on specific nutrient profiles, with a particular focus on the fatty acid composition of goat's milk, thereby delving deeper into these facets.

Author Contributions:.

Funding: The author's Yllka Visoka research-stay at the Hungarian University of Agriculture and Life Sciences, Budapest, Hungary was funded by the Erasmus+ program. This study was supported by the Ministry of Education, Science, Technology and Innovation of Kosovo (MESTI) and Austrian Development Agency (ADA) under the "Research based teaching grant" call action.

Institutional Review Board Statement:

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Authors gratefully acknowledge the support of Balkis Aouadi for their valuable assistance with the statistical analysis of the data presented in this paper.

Conflicts of Interest: The authors declare no conflict of interest.

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