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Comparative Analysis of the Nutritional Composition and Specific Gravity of Cow, Camel, and Goat Milk in Nangarhar Province Relative to Literature Standards for Human and Buffalo Milk

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ABSTRACT

Establishing objective physicochemical baselines for local dairy supplies is critical for quality control and public health. This study evaluates and compares the physical and macronutrient profiles of raw cow, camel, and goat milk samples from Nangarhar Province, benchmarked descriptively against archival literature data for human breast milk and buffalo milk. A cross-sectional analytical study was conducted using 60 independent raw milk samples (n=20 per species) collected from 15 local farms across Nangarhar Province. Standardized laboratory protocols quantified pH, fat, crude protein, and specific gravity at the Khatiz Dairy Processing Factory laboratory. Triplicate measurements (n =3) were taken. Human breast milk and buffalo milk values were compiled strictly from published reference literature for descriptive juxtaposition. Data were analyzed using a One-Way Analysis of Variance (ANOVA) and Welch's robust ANOVA ($p < 0.05$) via IBM SPSS v26.0. Empirical testing revealed a mean baseline pH of 6.75 ± 0.05 across the evaluated animal cohorts. Cow's milk exhibited a mean protein content of 3.50% ± 0.12%, fat content of 4.62% ± 0.18%, and a specific gravity of 1.032 ± 0.002. Camel's milk demonstrated 3.42% ± 0.15% protein, 4.30% ± 0.22% fat, and a specific gravity of 1.030 ± 0.003. Goat's milk exhibited the highest nutrient density with 4.82% ± 0.24% protein, 6.73% ± 0.35% fat, and an anomalously elevated specific gravity reading of 1.050 ± 0.005. One-Way ANOVA and post-hoc tracking confirmed that these species-specific variations were statistically significant ($p < 0.001$).Significant macronutrient and physical discrepancies exist among the evaluated local animal milk types. The anomalous specific gravity of 1.050 in goat milk indicates potential methodological factors, such as temperature-correction artifacts or supply-chain concentration effects, which require systematic validation. These regional baseline values provide preliminary data for localized dietary configurations, though direct clinical trials are necessary to validate therapeutic outcomes.

Keywords: pH Determination, Protein Quantification, Fat Quantification, Specific Gravity and Human Milk Benchmarking.

INTRODUCTION

The optimization of regional dietary strategies and the maintenance of dairy quality control systems necessitate rigorous evaluation of the physical and chemical properties of locally produced milk. Milk is a complex, dispersed colloidal system containing lipids, carbohydrates, proteins, structural water, minerals, and localized bioactive molecules suspended within an aqueous continuous phase (Fox & McSweeney, 2015); (Sherbon, 1988). Among these physical traits, milk density and specific gravity defined as the dimensionless ratio of milk density to the density of pure water at identical temperatures serve as traditional analytical benchmarks (Rolf et al., 2018); (Sherbon, 1988). These physical indicators are highly sensitive to shifts in the solids-not-fat (SNF) fraction and are frequently utilized by agricultural processing facilities to evaluate raw milk quality and screen for structural alterations (Kleyn, 1992); (Rolf et al., 2018).

In the agricultural landscape of Nangarhar Province, Afghanistan, smallholder dairy operations rely on diverse mammalian livestock, primarily cattle (*Bos*

Taurus), dromedary camels (*Camelus dromedarius*) and indigenous goats (*Capra hircus*)) (Habib et al., 2016). While global literature provides extensive physiological baselines for standardized Western breeds (Rolf et al., 2018), localized variations driven by distinct ecotypes, free-range browsing habits, and semi-arid environmental stressors create distinct compositional profiles (Habib et al., 2016). Furthermore, within regional pediatric nutrition discussions, animal-derived milks are frequently compared to human breast milk profiles to evaluate their structural suitability as dietary supplements (Martin et al., 2016).

Prior research has often focused heavily on isolated yields, leaving a distinct data gap regarding comprehensive, simultaneous statistical comparisons of these three sympatric livestock species under local management practices. This study aims to fill that gap by providing verified descriptive and inferential statistics for raw cow, camel, and goat milk in Nangarhar Province, evaluated under standardized laboratory parameters and cross-referenced with established international literature standards for human and buffalo milk.

Materials and Methods

1. **Sample Selection and Collection Procedure**:
A cross-sectional analytical study design was executed across Nangarhar Province. A total of 60 independent raw milk samples were collected, representing three distinct target species: Raw Cow's Milk (n=20) independent biological samples, Raw Camel's Milk (n=20) independent biological samples, and Raw Goat's Milk (n=20) independent biological samples. Samples were collected from 15 distinct smallholder farms situated within three agrarian districts: Beti Kot (arid pasture, primarily camels), Kama (intensive smallholder cattle production), and Surkh Rod (extensive mixed goat herds).
To minimize confounding systemic variations, inclusion criteria restricted sampling to clinically healthy, multiparous animals (2nd to 4th lactation cycle) evaluated in their mid-lactation stage (60–120 days postpartum). Animals showing signs of mastitis via visual screening or the California Mastitis Test (CMT) were excluded. Cattle were managed under semi-intensive configurations fed green fodder (Trifolium alexandrinum) and wheat straw. Camels were managed under extensive grazing setups browsing on native halophytic plants and Acacia foliage. Goats were maintained on traditional free-range grazing setups.

Raw milk was hand-milked during morning cycles (05:00 AM – 07:00 AM). Teats were sanitized with a 0.5% iodine solution and dried with single-use towels; the first three streams of foremilk were discarded. A 250 mL representative aliquot was collected per animal into sterile high-density polyethylene (HDPE) bottles, instantly transferred to insulated coolers packed with frozen gel packs (4°C to 6°C), and transported to the laboratory at the Khatiz Dairy Processing Factory within 3 hours of collection.

2. **Analytical Procedures and Instrument Calibration:**
All laboratory evaluations were conducted with three independent technical replicates (n=3) per sample to ensure empirical reproducibility. pH Determination: Measured using a digital benchtop pH meter (Model HI-2211, Hanna Instruments). The instrument was calibrated daily before testing using standard analytical buffer solutions at pH 4.01 and 7.01 at a controlled temperature of 20°C. Results are reported as standard dimensionless pH units.
3. **Specific Gravity**:
Evaluated using a standard Quevenne lactometer at a reference temperature of 20°C. The lactometer was calibrated using distilled water (reading 1.000 at 20°C). Specific gravity values are properly reported as a dimensionless ratio. Fat and Crude Protein Analysis: Total fat percentage was determined via the standard Gerber butyrometric method using species-specific Gerber pipettes and amyl alcohol reagents (Kleyn, 1992). Quantitative crude protein content was analyzed using a calibrated automated ultrasonic milk analyzer (Lacto scan SP), with validation performed on random duplicate subsets using the classic Kjeldahl nitrogen determination method (nitrogen-to-protein conversion factor of 6.38) (Kleyn, 1992). All measurements were conducted at a strictly maintained water-bath temperature of 20°C.
4. **Statistical Analysis**:
Experimental data were compiled and analyzed using IBM SPSS Statistics (Version 26.0). Descriptive statistics are expressed as means ± standard deviation (SD) based on the number of biological observations (n = 20 per species). Prior to inferential testing, data were evaluated for normality via the Shapiro-Wilk test ($p > 0.05$) and homogeneity of variances via Levene's test.

For parameters exhibiting homogenous variances (pH and protein), a parametric One-Way Analysis of Variance (ANOVA) was executed, followed by Tukey's Honestly Significant Difference (HSD) post-hoc test for pairwise comparisons. For specific gravity and lipid content where unequal variances were detected, Welch's robust ANOVA followed by the Games-Howell post-hoc test was implemented. Statistical significance was defined at $p < 0.05$. Human breast milk and buffalo milk values were excluded from the inferential models and used purely as external, descriptive reference benchmarks.

Results

1. **Physicochemical and Macronutrient Quantifications**:

The empirical analysis revealed significant structural differences across the animal cohorts. The mean pH value was highly uniform, tracking at 6.75 ± 0.05 for cows, 6.75 ± 0.04 for camels, and 6.75 ± 0.06 for goats.

Macronutrient profiles showed highly significant variations between the species. The mean protein and fat content of cow's milk was 3.50% ± 0.12% and 4.62% ± 0.18%, respectively, with a mean specific gravity of 1.032 ± 0.002. Camel's milk exhibited a mean protein content of 3.42% ± 0.15%, a fat content of 4.30% ± 0.22%, and a specific gravity of 1.030 ± 0.003. Goat's milk demonstrated the highest overall values, with a mean protein content of 4.82% ± 0.24%, a mean fat content of 6.73% ± 0.35%, and an unexpectedly elevated mean specific gravity reading of 1.050 ± 0.005.

Table 1: Physicochemical Parameters of Tested Animal Milk Samples in Nangarhar Province

Parameter	Cow Milk (n=20)	Camel Milk (n=20)	Goat Milk (n=20)	P-value (ANOVA)
pH (Units)	6.75 ± 0.05	6.75 ± 0.04	6.75 ± 0.06	p = 0.982
Protein (%)	3.50 ± 0.12 (a)	3.42 ± 0.15 (a)	4.82 ± 0.24 (b)	p < 0.001
Fat (%)	4.62 ± 0.18 (a)	4.30 ± 0.22 (a)	6.73 ± 0.35 (b)	p < 0.001
Specific Gravity	1.032 ± 0.002 (a)	1.030 ± 0.003 (a)	1.050 ± 0.005 (b)	p < 0.001

Note: Values represent Means ± Standard Deviation of biological replicates. Means within a row bearing different superscript letters (a, b) differ significantly ($p < 0.05$) based on post-hoc testing.

2. **Integration of Secondary Descriptive Reference Baselines**:

To provide a broad nutritional overview, Table 2 balances the experimental findings against secondary reference values derived from published clinical and food-composition literature for human breast milk and buffalo milk.

Table 2: Experimental Findings Juxtaposed with Secondary Literature Reference Ranges

Milk Type	Exp. Protein (%)	Lit. Protein Range (%)	Exp. Fat (%)	Lit. Fat Range (%)
Cow	3.50% ± 0.12%	3.20% – 3.60% [7]	4.62% ± 0.18%	3.50% – 4.50% [7]
Camel	3.42% ± 0.15%	3.00% – 3.90% [8]	4.30% ± 0.22%	3.40% – 5.40% [8]
Goat	4.82% ± 0.24%	3.10% – 3.80% [9]	6.73% ± 0.35%	3.50% – 4.50% [9]
Human (Ref)	[Not Analyzed]	~1.05 % [10]	[Not Analyzed]	~4.20 % [10]
Buffalo (Ref)	[Not Analyzed]	3.80% – 4.50% [11]	[Not Analyzed]	6.50% – 8.00% [11]

Note: Experimental values indicate metrics quantified directly in this study. Human and Buffalo milk values are derived strictly from the cited reference literature.

Discussion

1. **Critical Evaluation of the 1.050 Goat Milk Specific Gravity Anomaly**

The recorded mean specific gravity of 1.050 within the local goat milk cohort represents a substantial deviation from standard global reference baselines, which typically range between 1.028 and 1.032 (Park et al., 2007; Rolf et al., 2018). Theoretically, milk specific gravity is determined by the additive densities of its individual components: water (1.000), solids-not-fat (SNF) such as proteins, lactose, and minerals (~1.340), and lipids (~0.930) (Sherbon, 1988). Because lipids have a lower density than pure water, an elevated fat concentration, such as the observed 6.73% in this study, should mathematically depress the specific gravity of the liquid colloidal matrix (Fox & McSweeney, 2015); (Sherbon, 1988). Therefore, a simultaneous finding of high fat (6.73%) and an elevated specific gravity of 1.050 presents a stark physical and biochemical contradiction for unadulterated raw milk.

Several experimental, environmental, and methodological factors must be analyzed to explain this specific discrepancy Temperature Calibration Artifacts: Standard Quevenne lactometers are calibrated strictly for readings at a reference

temperature of 20°C (Kleyn, 1992); (Sherbon, 1988). If the raw caprine samples were analyzed at lower ambient laboratory temperatures in Nangarhar without applying a mathematical correction factor, fluid contraction would artificially inflate the lactometer reading, presenting a major procedural limitation. Supply-Chain Adulteration Practices: Because samples were obtained from local commercial production chains across Surkh Rod, the deliberate addition of high-density reconstitution solutes (such as skim milk powder, starch, or mineral salts) by smallholders to artificially offset water dilution and maintain market density targets cannot be ruled out (Kleyn, 1992).

Meniscus Interpretation: Visual parallax errors during high-throughput manual testing at the processing factory laboratory could introduce systematic data entry bias due to the high viscosity of rich caprine milk. Future regional investigations must deploy digital oscillating U-tube density meters to bypass manual lactometer limitations and resolve this metric definitively.

2. **Influence of Breed, Husbandry, and Feed on Macronutrients**

The experimental values obtained for cow milk (protein: 3.50%, fat: 4.62%) and camel milk (protein: 3.42%, fat: 4.30%) closely match the expected standard international ranges published by the FAO (2020) and Konuspayeva et al. (2009). However, the local goat milk cohort significantly exceeded standard global literature guidelines for both protein (4.82% vs. 3.10%–3.80%) and fat (6.73% vs. 3.50%–4.50%) (Park et al., 2007). This localized enrichment is heavily influenced by distinct agro-ecological and husbandry factors unique to eastern Afghanistan. The tested caprine animals included indigenous Asmari and Teddy goat breeds, which are highly adapted to the rugged, semi-arid terrain of Nangarhar Province (Habib et al., 2016). These specific ecotypes typically exhibit concentrated, low-volume solid yields as a physiological survival mechanism under climatic stress, producing milk with significantly higher nutrient concentration compared to high-yielding Western breeds (Morand-Fehr, 2005; Park et al., 2007).

Additionally, the dietary reliance on high-fiber native shrubs, crop residues, and halophytic vegetation within the Surkh Rod district dynamically alters volatile fatty acid (VFA) production ratios in the rumen (Habib et al., 2016; Morand-Fehr, 2005). This high-fiber foraging significantly enhances acetate and butyrate availability in the rumen, which are the primary precursors for de novo fatty acid synthesis in the mammary gland, thereby directly driving up the milk fat percentage compared to goats maintained on intensive, standard concentrate feeds (Morand-Fehr, 2005).

3. **Contextual Descriptive Juxtaposition with Reference Groups**

When evaluated against the descriptive literature baselines for human breast milk, clear evolutionary and physiological differences emerge. According to Ballard and Morrow (2013) and Martin et al. (2016), human breast milk features a remarkably low protein profile (~1.05%) but a highly developed carbohydrate (lactose) profile (~7.00%) tailored specifically for slow infant metabolic demands and rapid brain development. In contrast, all three local animal milks evaluated in this study possess substantially higher protein loads, which could cause elevated renal solute stress if introduced unmodified into infant diets (Martin et al., 2016).

Conversely, the elevated protein and lipid structures quantified in the local goat milk cohort closely match or exceed the high-density profiles found in published literature for buffalo milk (Ahmad et al., 2013). Buffalo milk traditionally represents a highly dense energy source with a fat range of 6.50%–8.00% (Ahmad et al., 2013). The fact that Nangarhar's goat milk approaches this level of rich macronutrient concentration (6.73% fat) highlights its vital role as a concentrated source of dietary energy and essential amino acids in rural agricultural communities, though its high solute load requires proper modifications if adapted for infant nutrition models (Martin et al., 2016; Park et al., 2007).

4. **Moderation of Therapeutic and Clinical Interpretations**

Prior literature suggests that camel milk contains distinct biomolecular factors, such as insulin-like proteins and protective immunoglobulins, which are studied for their potential utility in specialized dietary management and milk allergies (Konuspayeva et al., 2009). Similarly, the high lipid and protein density of goat milk, combined with smaller fat globule sizes, makes it a valuable structural and therapeutic component of rural food supplies (Park et al., 2007).

However, because this study evaluated strictly baseline physical and chemical parameters and did

not measure active clinical health outcomes, these potential benefits must be interpreted with extreme caution. These local values describe nutritional composition matrices rather than demonstrating clinical efficacy, which requires structured, longitudinal randomized controlled trials in public health contexts.

Limitations

Constraints to be considered:

Sample Size and Geography: The evaluation was limited to a cohort of 60 samples restricted to Nangarhar Province, which limits the direct extrapolation of these baselines to other agro-ecological zones of Afghanistan.

Husbandry Variations: Variations in specific breed configurations, exact day of lactation, and daily dry matter intake could not be tightly controlled across the participating smallholder farms due to the traditional nature of the local production systems.

Analytical Constraints: Testing relied on manual Quevenne lactometers and ultrasonic milk analyzers rather than high-precision mid-infrared (MIR) spectroscopy or gas chromatography, which are needed to confirm the exact fatty acid structures.

Reference Data Constraints: The comparison with human breast milk and buffalo milk relied entirely on secondary literature ranges rather than concurrent laboratory testing under identical environmental variables.

Conclusions and Recommendations

This study establishes preliminary physicochemical baselines for raw cow, camel, and goat milk across Nangarhar Province. A uniform mean pH baseline of 6.75 was observed across all tested animal species. Inferential analysis confirmed significant variations in nutrient density, with local goat milk exhibiting elevated fat (6.73%) and protein (4.82%) content. The observed specific gravity anomaly of 1.050 in goat milk points toward the strong influence of experimental variables or regional supply-chain factors rather than normal baseline physiology.

These findings provide objective values for regional food composition tables and dairy quality control frameworks in eastern Afghanistan. Recommendations for clinical applications such as dietary interventions for pediatric malnutrition or therapeutic protocols must be avoided until structured clinical outcomes are verified. Future research should prioritize expanded longitudinal sampling frames across Afghanistan utilizing digital density instrumentation and advanced chromatography to map seasonal and breed-specific composition shifts.

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