Postprint: Nutritional Value and Microbial Composition of Fresh Yak Milk and Yogurt from the Qinghai-Tibet Plateau Region

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Abstract

Yak milk is renowned for its high nutritional value, containing abundant proteins, fats, essential amino acids, unsaturated fatty acids, vitamins, and mineral elements. It serves as the fundamental milk source for herdsmen in the Qinghai-Tibet Plateau region and constitutes one of their primary economic sources. Yak yogurt exhibits even higher nutritional value, distinctive flavor and texture, and multiple probiotic functions, thereby earning widespread favor among herdsmen. This review primarily synthesizes research on the nutritional components, microbial composition, and probiotic functions—including antioxidant and cholesterol-lowering properties—of fresh yak milk and traditionally fermented yak yogurt in the Qinghai-Tibet Plateau region, fully elucidating the nutritional value of traditionally fermented yak yogurt and its crucial role in maintaining herdsmen' s health, thus providing reference materials for subsequent in-depth investigations into yak milk and dairy products.

Full Text

Nutritional Value and Microbial Composition of Yak Fresh Milk and Yogurt in the Qinghai-Tibetan Plateau Region

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Abstract

Yak milk is renowned for its high nutritional value, containing abundant protein, fat, essential amino acids, unsaturated fatty acids, vitamins, and mineral elements. As the foundational milk source for herders on the Qinghai-Tibetan Plateau, it also represents a primary economic resource for local communities. Fermented yak yogurt offers even higher nutritional value, distinctive flavor and texture, and multiple probiotic functions, making it highly favored among plateau herders. This review synthesizes research on the nutritional components, microbial composition, antioxidant properties, and cholesterol-lowering characteristics of yak fresh milk and traditionally fermented yak yogurt in the Qinghai-Tibetan Plateau region. We aim to fully elucidate the nutritional value of traditionally fermented yak yogurt and its crucial role in maintaining herder health, while providing reference materials for future in-depth studies on yak milk and dairy products.

Keywords: yak fresh milk; yak yogurt; nutritional value; microbial composition; probiotic function

Yaks constitute the primary livestock species in the Qinghai-Tibetan Plateau region, with yak milk accounting for 90% of milk consumption on the plateau and 15% of national milk consumption in China. This milk source is essential for the survival of Tibetan people and serves as a major economic resource [1]. Compared to other types of milk, yak milk contains higher levels of fat, protein, lactose, vitamins, and essential amino acids, features a greater variety of fatty acids, has lower cholesterol content, and exhibits certain antioxidant capacities, earning it the reputation of being the "cream of milk" [2]. In addition to direct consumption of fresh milk, Tibetan people traditionally process yak milk into butter tea, raw butter, cheese, and yogurt. Among these products, yak yogurt is consumed more frequently due to its superior flavor and texture after fermentation. During fermentation, the nutritional composition of yak milk remains largely unchanged except for lactose, which is converted into lactic acid, organic acids, and ethanol, thereby reducing the yogurt's pH. The unique climatic conditions of the Qinghai-Tibetan Plateau result in exceptionally distinctive microbial compositions in yogurt. Research has demonstrated that fermented yak yogurt contains substantial populations of lactic acid bacteria and yeasts, with beneficial lactic acid bacteria primarily belonging to the genus *Lactobacillus* [3]. Ding et al. [4] isolated and screened *Lactobacillus plantarum* Lp3 from yak yogurt and administered this strain to mice fed a high-cholesterol diet, achieving a serum cholesterol degradation rate of 73.3%. These findings indicate that yak milk not only provides essential nutrients such as protein, fat, fatty acids, amino acids, and vitamins, but also that the probiotic bacteria in its yogurt offer additional health benefits. Despite widespread consumption in Tibetan regions, yak milk products have not yet penetrated major markets in eastern developed regions due to transportation limitations and varying lifestyle habits across different areas. Future promotion of yak milk products could significantly increase income for Tibetan people, stimulate economic development in the Qinghai-Tibetan Plateau region, and allow more dairy consumers to experience the high nutritional value and probiotic benefits of yak milk products. This review examines the nutritional components, microbial composition, and probiotic functions of yak fresh milk and yogurt to provide a reference basis for future research on yak milk products.

1.1 Yak Fresh Milk

The nutrient content in yak fresh milk varies depending on lactation period, breed, and nutritional status. Yak colostrum contains significantly higher levels of protein (5.43%), fat (5.70%), and total amino acids (4.485%) compared to regular milk (4.84%, 4.57%, and 3.065%, respectively). Additionally, colostrum contains higher concentrations of essential amino acids including phenylalanine, methionine, leucine, isoleucine, and valine, as well as histidine, which is essential for children' s growth and development [5]. In the Wushaoling area of Tianzhu County, Gansu Province, yak colostrum (within 24 hours postpartum) contains protein, fat, lactose, and crude ash at 9.86%, 7.89%, 3.28%, and 1.21%, respectively. Vitamins A, E, C, and -carotene reach their peak concentrations within 24 hours postpartum and gradually decline with lactation time, while lactose content shows an increasing trend [6]. Cui et al. [7] analyzed yak milk from days 1-7 postpartum and found that various amino acid contents decreased over time, as did unsaturated fatty acid content, though the proportion of essential amino acids increased. These observations demonstrate that yak milk composition is influenced by lactation stage: as lactation progresses, milk yield gradually increases while nutrient concentrations decrease, but the proportion of essential amino acids rises.

He et al. [8] measured daily milk yield and nutrient composition of fresh milk from yak breeds in Maiwa Township and Zhongdian County, as well as from Gannan Tibetan Autonomous Prefecture, and two hybrid breeds (Maiwa yak × yellow cattle and Gannan yak × yellow cattle). The 4% fat-corrected milk (FCM) yield of the hybrid breeds was significantly higher than the average yield of pure yaks, with no significant differences in fat, protein, lactose, or crude ash content. Notably, yak milk from Zhongdian County contained 4.82% polyunsaturated fatty acids (PUFA), higher than that from Maiwa (3.99%) and Gannan (3.68%) yaks, along with higher levels of linolenic acid and conjugated linoleic acids (CLA). Guo et al. [9] reported that yak fresh milk contains dry matter (157-184 g/kg), fat (55-86 g/kg), protein (42-64 g/kg), lactose (33-58 g/kg), and crude ash (4-9 g/kg), compared to 114-120 g/kg, 25-35 g/kg, 30-35 g/kg, 45-50 g/kg, and 7 g/kg, respectively, in Holstein cow milk [10-11]. Yak milk contains significantly higher levels of dry matter, fat, and protein than

Holstein milk. Yak milk also surpasses cow, camel, and goat milk in dry matter, fat, non-fat solids, protein, and lactose content, with similar crude ash content. Since fat and protein content are two important indicators for evaluating milk quality, the significantly higher levels in yak milk indicate its superior quality .

The fatty acid composition of yak milk varies seasonally. In September, saturated fatty acid (SFA) content (58.63%) is significantly lower than in March (61.77%), July (62.30%), and November (64.92%), while monounsaturated fatty acid (MUFA) and PUFA contents peak in September at 33.90% and 7.33%, respectively [14]. Due to the plateau' s unique ecological environment, the grass growing season lasts only 90–120 days, with peak biomass in July and optimal quality in September, followed by withering in November. The high nutritional quality of September forage significantly enhances milk fatty acid content. Bett et al. [15] found that Holstein cow milk contains 62.09% SFA, 26.16% MUFA, and 4.81% PUFA—significantly lower than yak milk during good nutritional conditions. Cui et al. [16] analyzed yak milk from different altitudes and observed that SFA, MUFA, and PUFA contents increased with altitude, all exceeding those in commercial cow milk. Yak milk contains 21.7 g CLA per kg of fat, twice that of cattle and sheep milk and three times that of goat milk [17]. CLA effectively prevents cancer and diabetes, reduces body fat deposition, prevents atherosclerosis, and enhances immune function [18]. Vitamin contents in yak and other mammalian milks are shown in .

Yak milk contains high levels of vitamins C and E, contributing to its strong antioxidant capacity. Its vitamin A and D contents are significantly higher than in cow milk and fully meet human daily requirements, which may explain why Tibetan herders rarely show vitamin deficiency symptoms. Zhang et al. [19] found that Tibetans living at 4,300 m altitude had significantly higher blood levels of vitamins C and E than Han Chinese, likely due to consumption of yak milk rich in these vitamins. Since vitamins C and E possess antioxidant properties, drinking yak milk can enhance the body' s antioxidant capacity. Furthermore, yak milk is rich in mineral elements, with calcium, phosphorus, iron, zinc, manganese, and trace elements silver, chromium, and cadmium all significantly higher than in commercial milk products.

1.2 Yak Yogurt

Traditionally fermented yak yogurt (kurut) possesses unique flavor and texture with enhanced nutritional value. Traditional fermented yak yogurt from the Qinghai-Tibetan Plateau contains dry matter (143.0 g/L), fat (53.7 g/L), protein (54.4 g/L), lactose (23.4 g/L), crude ash (8.6 g/L), and energy (4.21 MJ/kg). Compared to fresh milk, most nutrients remain essentially unchanged, though fat and lactose contents decrease significantly due to microbial fermentation, where fat is broken down into fatty acids and lactose is converted into lactic acid, acetic acid, and ethanol, lowering the pH. Cow yogurt contains 123.0 g/L dry matter, 38.5 g/L fat, 34.7 g/L protein, 34.2 g/L lactose, 8.0 g/L crude ash, and 3.01 MJ/kg energy—lower in dry matter, fat, protein, crude ash, and energy, but significantly higher in lactose than yak yogurt .

Most Asian populations have low lactase levels, and lactose intolerance is common. Individuals who cannot synthesize lactase may experience diarrhea and other adverse symptoms when consuming large amounts of lactose, which disrupts the intestinal alkaline environment. Since fermentation breaks down substantial lactose, yak yogurt is more beneficial for lactose-intolerant individuals than cow yogurt, representing an excellent dairy alternative. Amino acid levels are similar between yak fresh milk and its fermented yogurt, with glutamic acid comprising the highest proportion (21.6% and 21.5%, respectively) and essential amino acids accounting for 40.9% and 40.8% of total amino acids [22]. Meanwhile, fatty acid profiles show no significant differences between fresh milk and yogurt, likely because microbial fermentation has minimal impact on fatty acid composition, thus preserving the advantage of high unsaturated fatty acid content [23]. Vitamin and mineral contents are also similar between fresh milk and yogurt, though vitamins A, E, and C levels remain higher than in cow yogurt [3,9,16].

2 Microbial Diversity in Yak Fresh Milk and Yogurt

Naturally fermented dairy products have a long history, and the combined action of lactic acid bacteria and yeasts, along with certain latent active amino acid conversion enzymes, creates unique flavors and textures [27]. Dairy products harbor diverse, abundant, and vigorous bacterial populations. While beneficial bacteria are common, pathogenic bacteria are also present, though most pathogens and spoilage microorganisms are suppressed by acids and antimicrobial substances produced by lactic acid bacteria during natural fermentation, substantially reducing their numbers. Common lactic acid bacterial genera in naturally fermented dairy products include *Lactobacillus*, *Lactococcus*, *Streptococcus*, *Bifidobacterium*, *Leuconostoc*, *Pediococcus*, *Enterococcus*, and *Weissella* [28-30].

2.1 Yak Fresh Milk

Due to relatively backward production levels in Tibetan regions, traditionally hand-milked raw yak milk contains higher quantities of *Escherichia coli* and *Staphylococcus aureus* than yogurt, both of which are pathogenic and can cause diarrhea, enteritis, and other diseases. Conversely, beneficial bacteria (lactic acid bacteria and yeasts) are present in lower numbers in fresh milk, though their content tends to increase with altitude [24]. Therefore, raw yak milk is not entirely suitable for direct consumption and has poorer sanitary conditions than yak yogurt. However, most pathogenic bacteria are eliminated by pasteurization, making commercialized yak fresh milk safe for consumption.

2.2 Yak Yogurt

The unique ecological environment of the Qinghai-Tibetan Plateau shapes the distinctive microbial composition and abundance in traditionally fermented yak yogurt. Zhang et al. [3] analyzed microbial composition in naturally fermented yak yogurt from the Qinghai Lake area and found average lactic acid bacteria content of 9.18 log (CFU/mL) and yeast content of 8.33 log (CFU/mL). Phenotypic analysis of ten naturally fermented yak yogurt samples from herders in Tibet and western Sichuan revealed that microorganisms were primarily lactic acid bacteria and yeasts, with viable counts reaching 10 and 10 CFU/mL, respectively. Purification and identification yielded 15 lactic acid bacterial strains (8 lactococci and 7 lactobacilli) and 8 yeast strains [31]. Chen et al. [32] compared naturally fermented yak yogurt with fermented Mongolian cow milk (FMCM) and found that yak yogurt contained (7.66$\pm$0.71) log (CFU/mL) lactic acid bacteria and (6.48$\pm$0.81) log (CFU/mL) yeasts—higher than FMCM, conferring antimicrobial and anti-spoilage properties. Sun et al. [33] purified and performed 16S rRNA sequencing on 143 naturally fermented yak yogurt samples from Qinghai, identifying 148 lactic acid bacterial strains (52 *Lactobacillus* and 96 *Lactococcus*), predominantly *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. Bao et al. [34] used 16S RNA sequencing and PCR-DGGE to analyze 88 yak yogurt samples from Maqu, Luqu, and Xiahe counties in Gansu, isolating 164 *Lactobacillus* strains (51.41%) including 87 *Lb. helveticus* and 31 *Lb. casei*, plus 155 lactococci (48.59%) including 39 *S. thermophilus* and 19 *Lc. lactis* subsp. *lactis*, and 49 *Leuconostoc* strains, with *Lb. helveticus* and *S. thermophilus* being most abundant. Ren et al. [35] similarly analyzed 38 yak yogurt samples from Inner Mongolia, identifying 211 lactic acid bacteria across 6 genera and 22 species/subspecies, including 117 *Lactobacillus* (55.45%) and 60 *L. delbrueckii* subsp. *bulgaricus* (28.43%). Zhong et al. [36] conducted 16S RNA diversity analysis of naturally fermented yak and cow yogurt, finding that yak yogurt had higher microbial diversity indices (Shannon: 2.35 vs. 2.20; Simpson: 0.69 vs. 0.62), indicating greater microbial community diversity. In yak yogurt, 78.44% of strains belonged to *Lactobacillus* and 14.08% to *Streptococcus*, whereas cow yogurt contained 64.69% *Lactobacillus*, 14.62% *Lactococcus*, and 10.29% *Streptococcus*.

High-throughput sequencing has recently been employed to study microbial community diversity in naturally fermented yak yogurt. One study using high-throughput pyrosequencing identified 112,173 high-quality bacterial and 90,980 high-quality fungal 16S RNA gene sequences. Analysis classified bacteria into 11 phyla [Figure 1: see original paper] and fungi into 5 phyla [Figure 2: see original paper], predominantly Firmicutes and Ascomycota. Redundancy analysis (RDA) identified 49 operational taxonomic units (OTUs) primarily as *Acinetobacter*, unidentified Bacteroidetes, *Lactobacillus*, unidentified Proteobacteria, *Streptococcus*, *Pantoea*, unidentified Firmicutes, *Propionibacterium*, *Lactococcus*, *Leuconostoc*, and Enterobacter [37]. Liu et al. [38] performed high-throughput sequencing on cow yogurt and found that most identified fungi and bacteria belonged to Firmicutes and Ascomycota, with *Lactobacillus* and *Pichia* being the dominant genera. In summary, microbial composition in yak yogurt varies with geographical location, altitude, and breed, showing distinct differences in diversity indices and taxonomic composition compared to cow yogurt. These compositional differences likely underlie the antioxidant and cholesterol-lowering probiotic functions.

3 Probiotic Functions of Yak Yogurt

The probiotic effects of lactic acid bacteria have attracted considerable attention. Yogurt represents the best source of probiotics, though only certain specific lactic acid bacteria strains possess probiotic efficacy [39]. Foodborne probiotics provide health benefits including antioxidant activity, improved gastrointestinal function, reduced blood cholesterol, and enhanced intestinal immunity [40]. When the body is stimulated by environmental stressors such as hypoxia, cold, intense UV radiation, or extreme pH, reactive oxygen species (ROS) accumulate excessively, damaging proteins, lipids, and nucleic acids, leading to cellular aging and death. The body responds by producing antioxidant enzymes including superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), and catalase (CAT) to mitigate ROS damage [41]. Numerous studies have demonstrated that certain lactic acid bacteria possess antioxidant capacity, and naturally fermented dairy products from plateau regions contain highly antioxidant lactic acid bacteria resources that maintain redox stability by modulating the antioxidant system [42-44]. Lactic acid bacteria strains from naturally fermented yak yogurt in western Sichuan' s Qinghai-Tibetan Plateau showed maximum superoxide anion (· O) scavenging rates of 58.8%, anti-lipid peroxidation rates of 67.3%, and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging rates of 48.6%. Ding et al. [45] screened 403 lactic acid bacteria strains from naturally fermented yak yogurt on the Qinghai-Tibetan Plateau and identified nine different species with high DPPH radical scavenging activity. *Lactobacillus delbrueckii* subsp. *bulgaricus* F17 exhibited the strongest radical scavenging capacity (59% hydroxyl radical and 54% superoxide anion) and high survival rate (58%). Administration of this strain to D-galactose-induced aging mice significantly increased GSH-Px activity in liver and serum and SOD activity in serum and brain.

Changes in human dietary patterns have made meat an essential food, but its high cholesterol content can elevate blood lipids and cause cardiovascular diseases such as arterial blockage. Although yak milk contains 6.5% fat and 220 mg/kg cholesterol, cardiovascular disease incidence remains low among Tibetan herders. Research has revealed that lactic acid bacteria in naturally fermented yak yogurt possess cholesterol-lowering effects. One study isolated 72 lactic acid bacterial strains with high water-soluble cholesterol degradation capacity, including 27 strains (37.5%) with 90–95% degradation rates, 30 strains (41.6%) with 80–90% degradation rates, and one strain with an exceptionally high degradation rate of 96.26% [46]. Ding et al. [4] screened *Lactobacillus plantarum* from naturally fermented yak yogurt with high cholesterol degradation and survival rates. Administration to mice fed high-cholesterol diets significantly reduced serum and liver cholesterol and triglyceride levels and decreased hepatic fat deposition, achieving a cholesterol degradation rate of 73.3%.

4 Conclusion

Yak milk is rich in fat, protein, vitamins, amino acids, and unsaturated fatty acids, while yak yogurt contains abundant probiotic lactic acid bacteria that not only meet nutritional needs but also provide antioxidant and cholesterol-lowering benefits. However, several challenges limit market expansion: yaks have short lactation periods and lower milk yields compared to dairy cows, and few processing enterprises exist, resulting in limited market circulation. To address these issues, traditional genetic breeding combined with modern molecular marker-assisted breeding techniques could potentially improve milk yield and lactation duration while maintaining adequate nutrient supply, ensuring sufficient milk sources to meet market demand and expand the yak milk product market. Current research has extensively investigated microbial diversity in yak yogurt, but studies on the probiotic mechanisms remain limited. Promising strains with strong antioxidant capacity and high cholesterol degradation rates require further in vivo validation to identify those with high degradation and survival rates for industrial yogurt production. Additionally, the biological regulation of intestinal microbiota composition by probiotics and their immunomodulatory mechanisms warrant further investigation.

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Note: Figure translations are in progress. See original paper for figures.