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

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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 constitutes the fundamental milk source for herdsmen in the Qinghai-Tibet Plateau region and represents one of their major economic sources. Yak yogurt possesses even higher nutritional value, distinctive flavor and texture, and multiple probiotic functions, thus being highly favored by local herdsmen. This paper primarily reviews research on the nutritional components, microbial composition, and probiotic functions—including antioxidant properties and cholesterol-lowering effects—of fresh yak milk and traditionally fermented yak yogurt from the Qinghai-Tibet Plateau region. It comprehensively reveals the nutritional value of traditionally fermented yak yogurt and its important role in maintaining herdsmen' s health, thereby providing a reference foundation for subsequent in-depth research on yak milk and dairy products.

Full Text

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

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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 dairy source for herders on the Qinghai-Tibetan Plateau, it also represents a primary economic resource for local communities. Fermented yak yogurt (kurut) 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 yogurt in the Qinghai-Tibetan Plateau region. We aim to fully elucidate the nutritional value of traditional fermented yak yogurt and its crucial role in maintaining herder health, while providing a reference foundation for future in-depth studies on yak milk and dairy products.

Keywords: yak fresh milk; kurut; 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 dairy source is essential for the survival of Tibetan people and serves as a major income source [1]. Compared to other types of milk, yak milk contains higher levels of fat, protein, lactose, vitamins, and essential amino acids, offers a greater variety of fatty acids, has lower cholesterol content, and exhibits certain antioxidant capacities, earning it the reputation of "the finest among milks" [2]. In addition to consuming fresh milk directly, Tibetans traditionally process yak milk into butter tea, raw butter, cheese, and yogurt. Among these products, fermented yak yogurt is consumed most frequently due to its superior flavor and texture after fermentation. During fermentation, microbial action converts lactose into lactic acid, organic acids, and ethanol, thereby reducing yogurt pH, while other nutrient levels remain largely unchanged. The unique climatic conditions of the Qinghai-Tibetan Plateau also foster exceptionally distinctive microbial compositions in yogurt. Research indicates that fermented yak yogurt contains substantial populations of lactic acid bacteria and yeasts, with beneficial lactobacilli being the predominant lactic acid bacteria [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 reduction rate of 73.3%. These findings demonstrate that yak milk not only provides essential nutrients such as protein, fat, fatty acids, amino acids, and vitamins, but that the probiotic bacteria in its yogurt may 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 substantially 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

Nutrient composition in yak fresh milk varies significantly depending on lactation stage, breed, and nutritional status. Yak colostrum contains 5.43% protein, 5.70% fat, and 4.485% total amino acids—substantially higher than mature milk (4.84%, 4.57%, and 3.065%, respectively). Essential amino acids for humans, including phenylalanine, methionine, leucine, isoleucine, and valine, as well as histidine (crucial for child growth and development), are all present at higher concentrations in colostrum [5]. In the Wushaoling area of Tianzhu County, Gansu Province, yak colostrum (within 24 hours postpartum) contains 9.86% protein, 7.89% fat, 3.28% lactose, and 1.21% crude ash, with vitamin A, vitamin E, vitamin C, and -carotene reaching peak levels within 24 hours postpartum before gradually declining with lactation time, though 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 levels, while the proportion of essential amino acids increased. These findings indicate that yak milk nutrient composition is influenced by lactation period: as lactation progresses and milk yield increases, most nutrient concentrations gradually decline, 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 Maixiang and Zhongdian counties and Gannan Tibetan Autonomous Prefecture, as well as from two hybrid breeds (yak × yellow cattle). The 4% fat-corrected milk (FCM) yield of the hybrid breeds significantly exceeded the average yield of pure yaks from the three regions, while fat, protein, lactose, and crude ash contents showed no significant differences. Notably, yak milk from Zhongdian County contained 4.82% polyunsaturated fatty acids (PUFA), higher than that from Maixiang (3.99%) and Gannan (3.68%), with correspondingly higher levels of linolenic acid and conjugated linoleic acids (CLA). Guo et al. [9] reported that yak fresh milk contains 157-184 g/kg dry matter, 55-86 g/kg fat, 42-64 g/kg protein, 33-58 g/kg lactose, and 4-9 g/kg crude ash, 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 thus 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 levels. Since fat and protein content are two key indicators of milk quality, the significantly higher levels in yak milk indicate its superior quality (Table 1).

Fatty acid composition in yak milk varies seasonally. Saturated fatty acid (SFA) content in September (58.63%) was significantly lower than in March (61.77%), July (62.30%), and November (64.92%), while monounsaturated fatty acid (MUFA) and PUFA contents peaked 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 milk contained 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 elevation, all exceeding levels in commercial cow milk. Yak milk contains 21.7 g CLA per kg fat, double that of cattle and sheep milk and triple 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 Table 2 .

Yak milk' s high vitamin C and E content contributes to its strong antioxidant capacity, while its vitamin A and D levels significantly exceed those in cow milk, fully meeting human daily requirements. Consequently, Tibetan herders rarely exhibit 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 vitamin-rich yak milk. Since vitamins C and E possess antioxidant properties, drinking yak milk can enhance the body' s antioxidant capacity. Additionally, 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 (Kurut)

Traditionally fermented yak yogurt possesses unique flavor and texture with enhanced nutritional value. Traditional fermented yak yogurt from the Qinghai-Tibetan Plateau contains 143.0 g/L dry matter, 53.7 g/L fat, 54.4 g/L protein, 23.4 g/L lactose, 8.6 g/L crude ash, and provides 4.21 MJ/kg energy. Compared to fresh milk, most nutrient levels remain stable, though fat and lactose contents decrease significantly due to microbial decomposition of fat into fatty acids and conversion of lactose into lactic acid, acetic acid, and ethanol, which lowers 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, with lower levels of dry matter, fat, protein, crude ash, and energy, but significantly higher lactose than yak yogurt (Table 3).

Human lactase levels are relatively low, and lactose intolerance is common in Asia, where individuals cannot synthesize sufficient lactase. High lactose intake can disrupt the intestinal alkaline environment, causing diarrhea and other adverse symptoms [21]. Since fermentation breaks down substantial lactose, yak yogurt is more beneficial for lactose-intolerant populations 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 at 21.6% and 21.5% of total amino acids, respectively, and essential amino acids accounting for 40.9% and 40.8% of total amino acids [22]. Meanwhile, fatty acid profiles show minimal differences between fresh milk and yogurt, likely because microbial fermentation has limited 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 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 distinctive flavors and textures [27]. Dairy products harbor diverse, abundant, and vigorous bacterial populations. While beneficial bacteria predominate, 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 yak raw milk contains higher counts 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, though their content tends to increase with altitude [24]. Therefore, yak raw milk is somewhat unsuitable for direct consumption and has poorer sanitary conditions than yak yogurt. However, most pathogens 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 Qinghai Lake and found average lactic acid bacteria content of 9.18 log(CFU/mL) and yeast content of 8.33 log(CFU/mL). Phenotypic characterization of ten naturally fermented yak yogurt samples from Tibetan and western Sichuan plateau herder households 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, including 8 lactococci and 7 lactobacilli, plus 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±0.71) log(CFU/mL) lactic acid bacteria and (6.48±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, isolating 148 lactic acid bacterial strains, including 52 *Lactobacillus* and 96 *Lactococcus*, predominantly *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*. Bao et al. [34] used 16S RNA sequencing and PCR-denaturing gradient gel electrophoresis to screen 88 yak yogurt samples from Maqu, Luqu, and Xiahe counties in Gansu Province, identifying 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] applied similar methods to 38 yak yogurt samples from Inner Mongolia, identifying 211 lactic acid bacterial strains across 6 genera and 22 species or 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 Shannon and Simpson diversity indices were higher in yak yogurt (2.35 vs. 2.20 and 0.69 vs. 0.62, respectively), 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 investigate microbial community diversity in naturally fermented yak yogurt. Studies 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 [Figure 1: see original paper]) and fungi into 5 phyla (Figure 2 [Figure 2: see original paper]), predominantly *Firmicutes* and *Ascomycota*. Redundancy analysis (RDA) identified 49 operational taxonomic units (OTUs), primarily *Acinetobacter*, unidentified *Bacteroidetes*, *Lactobacillus*, unidentified *Proteobacteria*, *Streptococcus*, *Pantoea*, unidentified *Firmicutes*, *Propionibacterium*, *Lactococcus*, *Leuconostoc*, and *Enterococcus* [37]. Liu et al. [38] used 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, yak yogurt microbial composition varies with geography, altitude, and breed, showing substantial differences from cow yogurt in diversity indices and taxonomic distribution. These compositional differences likely underlie its probiotic functions such as antioxidant activity and cholesterol reduction.

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 confer probiotic benefits [39]. Foodborne probiotics provide health benefits including antioxidant activity, improved gastrointestinal function, reduced blood cholesterol, and enhanced intestinal immunity [40]. When the body experiences environmental stressors such as low pressure, cold, intense UV radiation, or extreme pH, reactive oxygen species (ROS) accumulate extensively, damaging proteins, lipids, and nucleic acids and causing cellular aging and death. In response, the body produces antioxidant enzymes including superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), and catalase (CAT) to mitigate ROS damage [41]. Numerous studies demonstrate that certain lactic acid bacteria possess antioxidant capacity, and naturally fermented dairy products from high-altitude regions contain highly antioxidant lactic acid bacteria resources that maintain redox stability by modulating the antioxidant system [42–44]. Lactic acid bacterial strains from naturally fermented yak yogurt in western Sichuan plateau showed superoxide anion (· O) scavenging rates up to 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 bacterial 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 scavenging) 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 reveals that lactic acid bacteria in naturally fermented yak yogurt possess cholesterol-lowering effects. Seventy-two lactic acid bacterial strains with high water-soluble cholesterol degradation capacity were isolated, 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 a *Lactobacillus plantarum* strain 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 and Perspectives

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 confer probiotic benefits such as antioxidant activity and cholesterol reduction. However, the short lactation cycle and lower milk yield compared to dairy cows, combined with few yak milk processing enterprises, limit market circulation and promotional efforts. Therefore, applying traditional genetic breeding and modern molecular marker-assisted selection techniques may improve the low milk yield and short lactation period, ensuring adequate milk supply to meet market demands and expand the yak milk product market. Current research has extensively investigated microbial diversity in yak yogurt, but studies on probiotic functions remain limited. Strains with strong antioxidant capacity and high cholesterol degradation rates require further in vivo validation to select candidates with high degradation and survival rates for industrial yogurt production. Additionally, the biological regulation of intestinal microbiota composition by probiotics and their mechanisms of action on immune function warrant further investigation.

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