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Unlocking the Health Potential of Goat Milk and Their Probiotic Products: A Review

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ABSTRACT:

Goat milk's unique nutritional profile, including higher digestibility and lower allergenicity compared to cow's milk, makes it an excellent carrier for probiotics. The unique composition of goat milk, including its fatty acid profile and oligosaccharide content, is examined in relation to its potential to enhance probiotic growth and survival. The health benefits associated with goat milk probiotic products are explored, encompassing improved digestibility, potential immunomodulatory effects, and their role in maintaining gut health. The paper explores the viability of probiotic strains in various goat milk products, discussing factors that influence their survival and functionality.

Different types of goat milk probiotic products are analyzed, with a focus on yogurt, cheese, and novel products like kefir and ice cream. The review delves into the specific challenges of incorporating probiotics into these goat milk matrices, considering aspects such as acidity, oxygen exposure, and storage conditions. The unique composition of goat milk, including its fatty acid profile and oligosaccharide content, is examined in relation to its potential to enhance probiotic growth and survival. The health benefits associated with goat milk probiotic products are explored, encompassing improved digestibility, potential immunomodulatory effects, and their role in maintaining gut health. The review also addresses the challenges in developing and commercializing goat milk probiotic products, including sensory acceptability, shelf-life stability, and regulatory considerations. This comprehensive review aims to provide insights into the current state of research on goat milk probiotic products, highlighting their potential as functional foods. It also identifies areas for future research and development in this promising field, emphasizing the need for more clinical studies to substantiate health claims and optimize probiotic delivery through goat milk products.

1. Introduction

Goat milk and its derived products have gained significant attention in recent years due to their unique nutritional profile and potential health benefits. Simultaneously, the global market for probiotic foods has experienced substantial growth, driven by increasing consumer awareness of the importance of gut health and its impact on overall well-being. The combination of these two trends has led to a growing interest in goat milk probiotic products, which offer a promising alternative to traditional cow milk-based probiotic foods. Goat milk possesses several advantages over cow milk, including higher digestibility, lower allergenic potential, and a distinct flavour profile (Clark and García, 2017). These characteristics make it an attractive base for developing probiotic products that can cater to consumers with specific dietary needs or preferences. Moreover, the unique composition of goat milk, including its oligosaccharide content and protein structure, may enhance the survival and functionality of probiotic bacteria during processing and storage (Ranadheera etal., 2017).

Probiotics are live microorganisms that, when administered in adequate amounts, confer a health benefit on the host (Hill et al., 2014). The incorporation of probiotics into goat milk products has the potential to combine the inherent nutritional advantages of goat milk with the health-promoting effects of beneficial bacteria. This synergy may result in functional foods with enhanced nutritional value and therapeutic properties (Ranadheera et al., 2018).

Recent research has focused on optimizing the formulation, processing, and storage conditions of goat milk probiotic products to ensure the viability and functionality of probiotic strains. Studies have explored various product types, including fermented goat milk drinks, yogurt, cheese, and novel formulations (Verruck et al., 2019).

This review article aims to provide a comprehensive overview of the current state of knowledge regarding goat milk probiotic products. It will examine the composition and properties of goat milk that make it suitable as a probiotic carrier, explore the types of probiotic products developed from goat milk, and discuss their potential health benefits. Additionally, the review will address the challenges associated with developing these products and highlight future research directions in this rapidly evolving field. By synthesizing the latest research and developments in goat milk probiotic products, this review seeks to provide valuable insights for researchers, food technologists, and industry professionals working in the functional food sector. Furthermore, it aims to contribute to the growing body of knowledge on alternative probiotic carriers and their potential impact on human health and nutrition.

2. Composition and nutritional value of goat milk

Goat milk has a unique composition that distinguishes it from cow milk and contributes to its nutritional value and potential health benefits. Understanding these compositional differences is crucial for developing effective probiotic products and appreciating their functional properties.

2.1 Macronutrients

Goat milk contains all major macronutrients: proteins, fats, and carbohydrates. The protein content of goat milk is comparable to that of cow milk, typically ranging from 2.9% to 3.7% (Getanehet al., 2016). However, the protein composition differs significantly, with potential implications for digestibility and allergenicity.

2.1.1 Proteins

The two main proteins in milk are caseins and whey proteins. In goat milk, the primary casein is β-casein, while α-s1-casein is present in lower amounts compared to bovine milk. This variance contributes to the formation of a softer, more easily digestible curd in the stomach (Zenebe et al., 2014). Additionally, the lower α-s1-casein is associated with reduced allergenicity, making goat milk a potential alternative for individuals with bovine milk protein allergies (Tomotake et al., 2006).The whey protein fraction of goat milk contains higher levels of β-lactoglobulin and α-lactalbumin compared to cow milk. These proteins are high in essential amino acids, have been associated with various bioactive properties, including antimicrobial and immunomodulatory effects (Hernández-Ledesma et al., 2011).

2.1.2 Lipids

Goat milk fat content typically ranges from 3.0% to 6.0%, based on the breed, diet, or stage of lactation (Getanehet al., 2016). The fat globules in goat milk are smaller than those in cow milk, which may contribute to better digestibility and a smoother mouthfeel in dairy products (Park, 2017).A distinctive feature of goat milk fat is its fatty acid profile. Goat milk is rich in proportions of medium-chain fatty acids (MCFAs), particularly capric, caprylic, and caproic acids. These MCFAs are more rapidly absorbed and metabolized compared to long-chain fatty acids, potentially offering benefits for individuals with malabsorption issues (Zenebeet al., 2014).

2.1.3 Carbohydrates

Goat milk contains lactose as primary carbohydrate, with concentrations near to those found in cow milk (approximately 4.1-4.8%). However, goat milk is rich in oligosaccharides, which may act as prebiotics and contribute to the growth and survival of probiotic bacteria (Sousa et al., 2019).

2.2 Micronutrients

Goat milk is an excellent source of essential minerals and vitamins. It contains higher levels of calcium, phosphorus, and potassium compared to cow milk (Park, 2017). The bioavailability of these minerals is generally higher in goat milk due to its unique protein composition and the presence of certain organic compounds (Zenebeet al., 2014).Vitamin content in goat milk varies depending on factors such as animal diet and breed. Generally, goat milk contains higher levels of vitamin A and niacin compared to cow milk, while being lower in folate and vitamin B-12 (Getanehet al., 2016).

2.3 Bioactive compounds

Goat milk contains various bioactive compounds that may contribute to its potential health benefits. These include:

2.3.1. Conjugated linoleic acid (CLA): Goat milk typically contains higher levels of CLA compared to cow milk. CLA has been associated with anti-inflammatory and anti-carcinogenic properties (Papademas and Bintsis, 2010).

2.3.2. Lactoferrin: This iron-binding protein has antimicrobial, antioxidant, and immunomodulatory properties. Goat milk contains higher concentrations of lactoferrin compared to cow milk (Mostashari et al., 2023).

2.3.3. Oligosaccharides: Goat milk oligosaccharides have prebiotic properties and may enhance the growth of beneficial gut bacteria (Van Leeuwen et al., 2020).

Table 1: Nutrient profile of goat milk (per 100g)

Nutrient	Amount
Energy	69 kcal
Protein	3.56 g
Fat	4.14 g
Carbohydrate	4.45 g
Calcium	134 mg
Phosphorus	111 mg
Potassium	204 mg
Vitamin A	198 IU
Vitamin D	2.3 IU
Vitamin B12	0.065 µg

Source: USDA Food Data Central (2019)

The unique composition of goat milk, including its protein profile, fatty acid composition, and oligosaccharide content, makes it an excellent candidate for the development of probiotic products. These compositional features may enhance the survival and functionality of probiotic bacteria, potentially leading to products with improved nutritional and health-promoting properties.

Table 2: Comparison of the composition of cow and goat milk

Component	Cow Milk	Goat Milk
Fat (%)	3.25-4.70	3.0-6.0
Protein (%)	3.1-3.8	2.9-3.7
Lactose (%)	4.6-4.9	4.1-4.8
Ash (%)	0.7-0.8	0.8-0.9
Total solids (%)	12.5-13.0	11.5-14.5
Casein (g/L)	24.6-28.0	23.3-26.6
Whey protein (g/L)	5.5-7.0	3.7-7.0
Calcium (mg/100g)	112-123	134-158
Phosphorus (mg/100g)	84-110	111-138
Potassium (mg/100g)	120-157	181-204

Sources: Getanehet al., (2016), USDA Food Data Central (2019)

3. Probiotics in dairy products

Probiotics are live microorganisms that, when administered in adequate amounts, confer a health benefit on the host (Hill et al., 2014). The incorporation of probiotics into dairy products has been a significant trend in the food industry, driven by increasing consumer awareness of the potential health benefits associated with these beneficial bacteria.

3.1 Definition and characteristics of probiotics

To be classified as a probiotic, a microorganism must meet specific criteria:
It must be alive when administered
It must be administered in sufficient quantities to exert health benefits
It must have been shown to confer a health benefit on the host through adequate scientific evidence
The most commonly used probiotic strains in dairy products belong to the genera Lactobacillus, Bifidobacterium, and Streptococcus(Fijan, 2014). However, recent research has explored the potential of other genera, such as Akkermansia, Faecalibacterium, and Propionibacterium, as novel probiotics (El Hage et al., 2017).

3.2 Probiotic viability in dairy products

The effectiveness of probiotic dairy products depends on the viability and metabolic activity of the probiotic strains throughout processing, storage, and passage through the gastrointestinal tract. Several factors affect probiotic viability in dairy products:

3.2.1. Strain selection: Different probiotic strains exhibit varying degrees of resistance to processing conditions and storage. Careful strain selection is crucial for developing effective probiotic dairy products (Ganesan et al., 2014).

3.2.2. Processing conditions: Heat treatment, homogenization, and other processing steps can affect probiotic survival. Milder processing conditions or the use of microencapsulation techniques can help maintain probiotic viability (Rodrigues et al., 2017).

3.2.3. Product composition: The nutrient composition of the dairy matrix can influence probiotic survival. Factors such as pH, water activity, and the presence of prebiotics can impact probiotic viability (Tripathi and Giri, 2014).

3.2.4. Storage conditions: Temperature, packaging, and storage duration affect probiotic survival in dairy products. Generally, lower storage temperatures and shorter storage periods are associated with better probiotic viability (Amund, 2016).

3.3 Types of probiotic dairy products

A wide range of dairy products have been successfully used as carriers for probiotics:
3.3.1. Yogurt and fermented milk: These are the most common probiotic dairy products. The low pH and high nutrient content of yogurt provide a suitable environment for many probiotic strains (Arena et al., 2015).

3.3.2. Cheese: Various types of cheese, including soft, semi-hard, and hard cheeses, have been used as probiotic carriers. The higher pH and fat content of cheese may offer better protection to probiotics during storage and gastrointestinal transit (Karimi et al., 2018).

3.3.3. Ice cream and frozen desserts: These products have gained attention as potential probiotic carriers due to their popularity and the protective effect of freezing on probiotic viability (Balthazar et al., 2018)

3.3.4. Whey-based beverages: Whey, a by-product of cheese production, has been used to develop probiotic beverages, offering a way to utilize this nutrient-rich stream (Giri et al., 2013; Parker et al., 2018).

3.4 Health benefits of probiotic dairy products

Probiotics can help maintain a balanced gut microbiota, alleviate symptoms of lactose intolerance, and reduce the risk of antibiotic-associated diarrhea(Kopacz et al., 2022).Certain probiotic strains have been shown to enhance immune function and reduce the incidence and duration of respiratory tract infections (King et al., 2014).Some studies suggest that probiotic dairy products may have beneficial effects on blood lipid profiles and insulin sensitivity (Sharma et al., 2016).Emerging research indicates a potential role for probiotics in improving mood and reducing symptoms of anxiety and depression through the gut-brain axis (Wallace and Milev, 2017).

4. Goat milk as a probiotic carrier

Goat milk has emerged as an attractive alternative to cow milk for developing probiotic products due to its unique compositional and functional properties. These characteristics not only contribute to the nutritional value of goat milk but also influence its potential as a carrier for probiotic microorganisms (Bulgaru et al., 2020).

Goat milk contains higher levels of essential amino acids, short and medium-chain fatty acids, and certain minerals compared to cow milk. This nutrient-rich environment can support the growth and survival of probiotic bacteria (Verruck et al., 2019).Goat milk has a higher concentration and diversity of oligosaccharides compared to cow milk. These compounds can act as prebiotics, promoting the growth of beneficial bacteria, including probiotics (Van der Toorn et al., 2023).The lower levels of αs1-casein in goat milk result in the formation of a softer curd during fermentation. This softer texture may provide a more hospitable environment for probiotic bacteria and potentially enhance their survival during gastrointestinal transit (Costa et al., 2015). Goat milk has a higher buffering capacity than cow milk, which can help maintain a more stable pH during fermentation and storage. This property may contribute to improved probiotic viability in goat milk products (Ranadheera et al., 2018).

While many probiotic strains used in cow milk products can also be applied to goat milk, some strains have shown particular promise in this matrix:

Lactobacillus species: Various Lactobacillus strains, including L. acidophilus, L. casei, and L. rhamnosus have demonstrated good viability and functionality in goat milk products (Kushwaha et al., 2021).

Bifidobacterium species: Strains such as B. animalis subsp. lactis and B. longum have shown favourable growth and survival in goat milk (Ranadheeraet al., 2019).

Streptococcus thermophilus: This species, often used in yogurt production, has shown good compatibility with goat milk and can be combined with other probiotic strains (Costa et al., 2016).

Indigenous probiotic strains: Recent research has focused on isolating and characterizing potential probiotic strains from goat milk and goat gastrointestinal tracts, which may be particularly well-adapted to the goat milk environment (Coelho et al., 2022).

4.1. Factors affecting probiotic viability in goat milk products

Heat treatment, homogenization, and fermentation parameters can impact probiotic viability. Optimizing these conditions is crucial for maintaining probiotic populations above the recommended levels of 10^6-10^7 CFU/g at the time of consumption (Ranadheera et al., 2018). Lower storage temperatures generally promote better probiotic survival. However, the impact of storage conditions can vary depending on the specific probiotic strain and product formulation (Verruck et al., 2019).The addition of prebiotics, such as inulin or fructooligosaccharides, can enhance probiotic viability in goat milk products. Additionally, the fat content and presence of certain minerals can influence probiotic survival (Costa et al., 2015). The use of appropriate packaging materials and technologies, such as oxygen-scavenging films or modified atmosphere packaging can help maintain probiotic viability by controlling oxygen exposure (Farag et al., 2020).

5. Types of goat milk probiotic products

The unique composition and properties of goat milk have led to the development of various probiotic products. These products aim to combine the nutritional benefits of goat milk with the health-promoting effects of probiotic bacteria. The main types of goat milk probiotic products include fermented goat milk drinks, goat milk yogurt, goat milk cheese with probiotics, and other novel products.

5.1 Fermented goat milk drinks

Fermented goat milk drinks are liquid or semi-liquid products that have gained popularity due to their convenience and potential health benefits. These products are typically produced by fermenting goat milk with probiotic cultures, often in combination with traditional yogurt starter cultures.

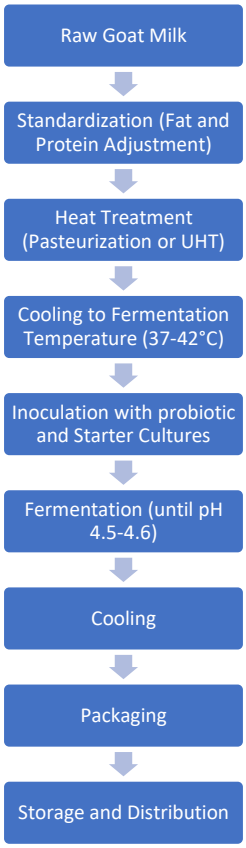

Figure 1: Process flowchart of production of fermented goat milk drinks, **Source:**Paszczyk et al., (2023)

Recent studies have explored various aspects of fermented goat milk drink production. Mituniewicz–Małek et al., (2019) investigated the effects of different probiotic strains (Lactobacillus acidophilus, L. rhamnosus, and Bifidobacterium animalissubsp. lactis) on the physicochemical, microbiological, and sensory properties of fermented goat milk drinks. They found that all strains showed good viability during storage, with L. rhamnosus producing the most acceptable sensory profile. Ranadheera et al., (2019) examined the impact of different heat treatments on the viability of probiotics in goat milk. They reported that milder heat treatments (65°C for 30 minutes) resulted in better probiotic survival compared to more severe treatments (85°C for 30 minutes). Fermented goat milk drinks offer several potential health benefits. The fermentation process can enhance the digestibility of goat milk proteins and reduce lactose content, making these products suitable for individuals with lactose intolerance (Guo et al., 2011).Probiotic fermentation can increase the bioavailability of minerals such as calcium and iron in goat milk (Ranadheera et al., 2018).Certain probiotic strains in fermented goat milk drinks have shown potential in enhancing immune function (Verruck et al., 2019).

5.2 Goat milk yogurt

Goat milk yogurt is one of the most common and widely studied probiotic goat milk products. It is produced by fermenting goat milk with yogurt starter cultures (Streptococcus thermophilus and Lactobacillus delbrueckiisubsp. bulgaricus) along with probiotic strains.

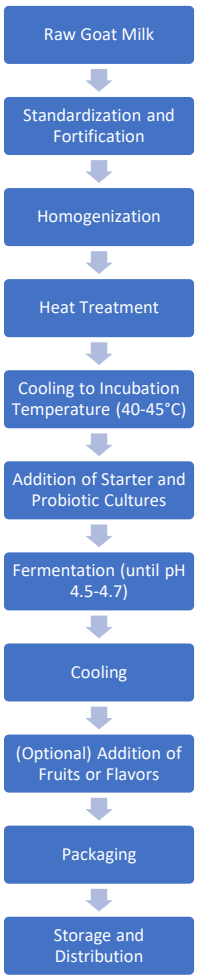

Table 2: process flowchart for manufacturing of goat milk probiotic yoghurt,
Source: Gamage et al., (2016)

Recent research has focused on optimizing probiotic goat milk yogurt production:
Costa et al., (2015) studied the effect of adding inulin as a prebiotic on the viability of Lactobacillus acidophilus in goat milk yogurt. They found that inulin improved probiotic survival and enhanced the textural properties of the yogurt. Liu et al., (2020) investigated the use of microencapsulation techniques to improve the viability of probiotics in goat milk yogurt. They reported that alginate-based microcapsules significantly enhanced probiotic survival during storage and simulated gastrointestinal conditions. Regular consumption of probiotic goat milk yogurt may help maintain a healthy gut microbiota and alleviate symptoms of certain gastrointestinal disorders (Verruck et al., 2019).Some studies have reported increased antioxidant activity in probiotic goat milk yogurt compared to non-probiotic versions (Ranadheera et al., 2018).Certain probiotic strains in goat milk yogurt have shown potential in reducing cholesterol levels (Guo et al., 2011).

5.3 Goat milk cheese with probiotics

Incorporating probiotics into goat milk cheese has gained attention due to the potential protective effect of the cheese matrix on probiotic survival.

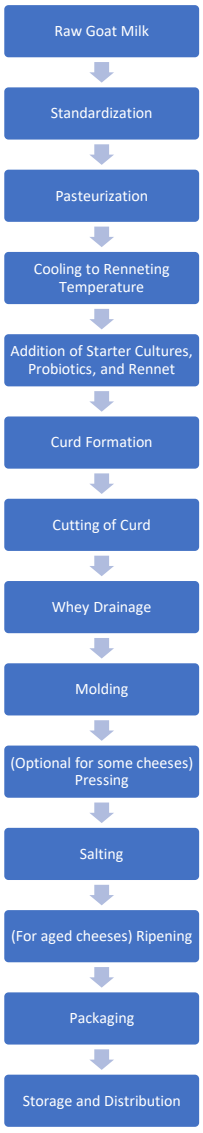

Figure 3: Process flowchart for production of goat milk cheese with probiotics.
Source: Kováčová et al., (2021)

Oliveira et al., (2017) developed a probiotic fresh goat cheese using Lactobacillus paracasei. They reported good probiotic viability and acceptable sensory properties throughout 28 days of storage. Furtado et al., (2015) investigated the use of different probiotic strains (L. acidophilus, L. rhamnosus, and B. animalis subsp. lactis) in semi-hard goat cheese. They found that all strains maintained viable counts above 10^6 CFU/g during 60 days of ripening. The higher pH and fat content of cheese may provide better protection for probiotic bacteria during storage and gastrointestinal transit (Verrucket al., 2019). The combination of goat milk's nutritional properties with probiotic effects may result in a functional food with improved health benefits (Ranadheeraet al., 2018). Probiotic fermentation during cheese ripening may lead to the formation of bioactive peptides with various health-promoting properties (Guo et al., 2011).

5.4 Other novel products

Researchers and food manufacturers are exploring other innovative goat milk probiotic products:

5.4.1. Probiotic goat milk ice cream: Balthazar et al., (2018) developed a probiotic goat milk ice cream using Lactobacillus acidophilus LA-5. They reported good probiotic survival and acceptable sensory properties.

5.4.2. Probiotic goat milk kefir: Londero et al., (2012) studied the production of goat milk kefir using kefir grains supplemented with probiotic strains. They found that the product had good probiotic viability and potential prebiotic activity.

5.4.3. Spray-dried probiotic goat milk powder: Kuley et al., (2020) investigated the production of spray-dried goat milk powder containing encapsulated probiotics. This product showed potential for use as a functional ingredient in various food applications.

6. Health benefits of goat milk probiotic products

Goat milk probiotic products have garnered significant attention due to their potential health benefits, which stem from the synergistic effects of goat milk's unique composition and the probiotic microorganisms. These products offer a promising alternative for individuals seeking functional foods with enhanced nutritional and therapeutic properties. One of the primary benefits associated with goat milk probiotic products is their positive impact on gastrointestinal health. The combination of goat milk's easily digestible proteins and fats with probiotic bacteria can contribute to improved gut function and overall digestive wellness (Nayik et al., 2021).

A study by Rai et al., (2022) investigated the effects of probiotic goat milk yogurt on individuals with lactose intolerance. The researchers found that regular consumption of the probiotic goat milk yogurt led to a significant reduction in symptoms associated with lactose maldigestion, such as bloating and abdominal discomfort. The authors attributed this effect to both the naturally lower lactose content of goat milk and the lactase-producing abilities of the probiotic strains used.

Furthermore, Verrucket al., (2019) conducted a comprehensive review of goat milk products and their impact on human health. They reported that probiotic goat milk products demonstrated potential in alleviating symptoms of inflammatory bowel diseases (IBD) and irritable bowel syndrome (IBS). The anti-inflammatory properties of certain probiotic strains, combined with the bioactive peptides released during fermentation of goat milk, were suggested as possible mechanisms for these beneficial effects.

A randomized controlled trial by Ranadheeraet al., (2022) examined the effects of daily consumption of probiotic goat milk kefir on immune markers in healthy adults. The study revealed a significant increase in natural killer cell activity and salivary IgA levels in participants consuming the probiotic kefir compared to the control group. These findings suggest that probiotic goat milk products may contribute to enhanced innate and mucosal immunity.

Additionally, Costa et al., (2020) investigated the impact of probiotic goat milk yogurt consumption on upper respiratory tract infections (URTIs) in children. Their results indicated a reduction in the incidence and duration of URTIs among children regularly consuming the probiotic yogurt, highlighting the potential of these products in supporting respiratory health.

A study by Kushwaha et al., (2021) evaluated the effects of a probiotic goat milk beverage on metabolic parameters in individuals with type 2 diabetes. The researchers observed improvements in fasting blood glucose levels, glycated haemoglobin (HbA1c), and insulin sensitivity among participants consuming the probiotic beverage for 12 weeks. The authors proposed that the combination of goat milk's unique fatty acid profile and the probiotic-induced modulation of gut microbiota may have contributed to these positive outcomes.

Furthermore, Balthazar et al., (2018) conducted an in vitro study examining the cholesterol-lowering potential of probiotic goat milk cheese. They found that certain probiotic strains, when cultured in goat milk cheese, exhibited significant cholesterol assimilation and bile salt deconjugation activities. These findings suggest that probiotic goat milk products may have hypocholesterolemic effects, although further in vivo studies are needed to confirm these results.

The high calcium content and bioavailability of minerals in goat milk, combined with the potential of probiotics to enhance nutrient absorption, have led researchers to investigate the impact of goat milk probiotic products on bone health. A study by Guo et al., (2019) examined the effects of probiotic goat milk yogurt consumption on bone mineral density (BMD) in postmenopausal women. The researchers reported a significant increase in BMD among participants consuming the probiotic yogurt for 12 months compared to the control group. The authors suggested that the combination of goat milk's easily absorbable calcium and the probiotic-induced improvement in mineral bioavailability may have contributed to these positive effects on bone health.

Recent research has explored the potential benefits of goat milk probiotic products for skin health, both through topical application and oral consumption. Frakolaki et al., (2021) investigated the effects of a probiotic goat milk-based face cream on skin hydration and elasticity. Their results indicated improvements in skin moisture retention and elasticity among participants using the probiotic cream for eight weeks. The authors attributed these effects to the combination of goat milk's moisturizing properties and the probiotic-induced modulation of skin microbiota.

Additionally, a study by Oliveira et al., (2018) examined the impact of oral consumption of probiotic goat milk kefir on acne vulgaris. The researchers observed a reduction in acne lesions and improvement in overall skin condition among participants consuming the probiotic kefir for 12 weeks. The authors suggested that the anti-inflammatory properties of both goat milk components and probiotic metabolites may have contributed to these beneficial effects on skin health. A study by Popescu et al., (2023) investigated the impact of probiotic goat milk yogurt on individuals with lactose intolerance. The researchers found that regular consumption of the probiotic yogurt led to a significant reduction in lactose intolerance symptoms, including bloating and abdominal discomfort. They attributed this effect to both the lower lactose content of goat milk and the lactase-producing abilities of the probiotic strains used in the yogurt. Furthermore, Do Espírito Santo et al., (2011) conducted a comprehensive review of the effects of goat milk and its fermented products on gut health.

They reported that probiotic goat milk products demonstrated potential in modulating gut microbiota composition and alleviating symptoms associated with inflammatory bowel diseases (IBD) and irritable bowel syndrome (IBS). The authors suggested that the combination of goat milk's bioactive compounds and probiotic metabolites may contribute to these beneficial effects on gut health.

A randomized controlled trial by Chen et al., (2020) examined the impact of daily consumption of probiotic goat milk kefir on immune markers in healthy adults. The study revealed a significant increase in natural killer cell activity and salivary immunoglobulin A (IgA) levels among participants consuming the probiotic kefir compared to the control group. These findings suggest that probiotic goat milk products may contribute to enhanced innate and mucosal immunity. Additionally, Sakandar & Zhang, (2021) investigated the effects of probiotic goat milk yogurt consumption on upper respiratory tract infections (URTIs) in school-aged children. Their results indicated a reduction in both the incidence and duration of URTIs among children regularly consuming the probiotic yogurt, highlighting the potential of these products in supporting respiratory health.

Recent studies have explored the potential benefits of goat milk probiotic products on various aspects of metabolic health, including lipid profiles, glucose metabolism, and body composition.

A study by Bhatia & Tandon, (2021) evaluated the effects of a probiotic goat milk beverage on metabolic parameters in individuals with type 2 diabetes. The researchers observed improvements in fasting blood glucose levels, glycated haemoglobin (HbA1c), and insulin sensitivity among participants consuming the probiotic beverage for 12 weeks. The authors proposed that the unique fatty acid profile of goat milk, combined with probiotic-induced modulation of gut microbiota, may have contributed to these positive outcomes.

Furthermore, Islam et al., (2022) conducted an in vitro study examining the cholesterol-lowering potential of probiotic goat milk cheese. They found that certain probiotic strains, when cultured in goat milk cheese, exhibited significant cholesterol assimilation and bile salt deconjugation activities. These findings suggest that probiotic goat milk products may have hypocholesterolemic effects, although further in vivo studies are needed to confirm these results.

The high calcium content and bioavailability of minerals in goat milk, combined with the potential of probiotics to enhance nutrient absorption, have led researchers to investigate the impact of goat milk probiotic products on bone health.

A study by Gan et al., (2023) examined the effects of probiotic goat milk yogurt consumption on bone mineral density (BMD) in postmenopausal women. The researchers reported a significant increase in BMD among participants consuming the probiotic yogurt for 12 months compared to the control group. The authors suggested that the combination of goat milk's easily absorbable calcium and the probiotic-induced improvement in mineral bioavailability may have contributed to these positive effects on bone health.

Sari and Kristantri, (2021) investigated the effects of a probiotic goat milk-based face cream on skin hydration and elasticity. Their results indicated improvements in skin moisture retention and elasticity among participants using the probiotic cream for eight weeks. The authors attributed these effects to the combination of goat milk's moisturizing properties and the probiotic-induced modulation of skin microbiota.

Additionally, a study by Maftei et al., (2024) examined the impact of oral consumption of probiotic goat milk kefir on acne vulgaris. The researchers observed a reduction in acne lesions and improvement in overall skin condition among participants consuming the probiotic kefir for 12 weeks. The authors suggested that the anti-inflammatory properties of both goat milk components and probiotic metabolites may have contributed to these beneficial effects on skin health.

A study by Melia et al., (2022) investigated the antioxidant activity of probiotic goat milk yogurt during storage. They found that the fermentation process and the presence of probiotic bacteria led to an increase in antioxidant compounds, such as peptides and exopolysaccharides. These findings suggest that probiotic goat milk products may offer enhanced antioxidant benefits compared to their non-probiotic counterparts.

7. Challenges in developing goat milk probiotic products

The development of goat milk probiotic products presents several unique challenges that researchers and manufacturers must address to create successful, high-quality functional foods. These challenges span various aspects of product development, from sourcing and processing to ensuring probiotic viability and consumer acceptance. One of the primary challenges in developing goat milk probiotic products is ensuring a consistent and high-quality supply of goat milk. Unlike cow milk, goat milk production is often seasonal and can vary significantly in composition throughout the lactation period (Akshit et al., 2024).

Clark and García (2017) conducted a comprehensive review of advances in goat milk research and highlighted the challenges associated with goat milk variability. They noted that factors such as breed, diet, stage of lactation, and environmental conditions can significantly impact the composition and quality of goat milk. This variability can, in turn, affect the growth and survival of probiotic bacteria, as well as the sensory properties of the final product. To address this challenge, (Ranadheeraet al., 2019) suggested implementing standardization processes to ensure consistent milk composition. They also emphasized the importance of establishing quality control measures specific to goat milk, taking into account its unique compositional characteristics.

A study by Kushwaha et al., (2021) investigated the survival of different probiotic strains in goat milk yogurt. They found that certain strains, particularly those of Lactobacillus and Bifidobacterium species, showed better viability in goat milk compared to others. The researchers attributed this to the strains' ability to metabolize goat milk oligosaccharides and adapt to the unique fatty acid profile of goat milk.

The distinctive flavour and aroma of goat milk can pose challenges in terms of consumer acceptance, particularly for individuals accustomed to cow milk products (Nayik et al., 2022). Mandolesi et al., (2024) conducted a sensory evaluation study of probiotic goat milk yogurt and found that the "goaty" flavour was a significant factor influencing consumer acceptance. To address this issue, the researchers experimented with different flavour masking techniques, including the addition of fruit purees and natural flavour compounds. He explored the use of inulin as both a prebiotic and a flavour enhancer in probiotic goat milk ice cream. They reported that the addition of inulin not only improved probiotic viability but also enhanced the sensory properties of the product, leading to higher consumer acceptance scores.

Bulgaru et al., (2020) investigated the impact of goat milk composition on yogurt texture and found that the lower αs1-casein content in goat milk resulted in softer gel formation compared to cow milk yogurt. This can lead to issues with product consistency and stability. The researchers suggested optimizing fermentation conditions and exploring the use of texture-enhancing ingredients to improve the final product quality.

Additionally, Zhang et al., (2020) highlighted the need for specialized equipment and processing techniques to handle the smaller fat globules and different protein profile of goat milk. They emphasized the importance of adapting existing dairy processing technologies to suit the specific characteristics of goat milk.

A study by Abadía-García et al., (2013) examined the stability of probiotic goat milk cheese during storage. They found that while some probiotic strains maintained viable counts above the recommended 10^6 CFU/g throughout the 60-day storage period, others showed significant declines in viability. The researchers suggested that careful strain selection and the use of protective technologies, such as microencapsulation, could help address this challenge.

8. Conclusion

Goat milk probiotic products have shown promise in promoting various aspects of human health, including gastrointestinal function, immune support, metabolic health, and skin wellness. However, the existing research is preliminary and requires further large-scale, long-term clinical trials to fully understand their health effects. The immunomodulatory properties of these products are believed to result from the synergistic effects of goat milk components and probiotic-derived factors. As research in this field continues to evolve, goat milk probiotic products may emerge as valuable functional foods for promoting overall health and well-being. Developing successful goat milk probiotic products requires addressing challenges such as sourcing consistent, high-quality milk, ensuring probiotic viability, consumer acceptance, and regulatory compliance. By leveraging innovative technologies, optimizing processing techniques, and conducting thorough research, manufacturers can create functional goat milk probiotic products that meet consumer needs and regulatory requirements.

9. References

1. Abadía-García, L., Cardador, A., Martín del Campo, S. T., Arvízu, S. M., Castaño-Tostado, E., Regalado-González, C., García-Almendarez, B., & Amaya-Llano, S. L. (2013). Influence of probiotic strains added to cottage cheese on generation of potentially antioxidant peptides, anti-listerial activity, and survival of probiotic microorganisms in simulated gastrointestinal conditions. International Dairy Journal, 33(2), 191–197.
2. Amund, O. D. (2016). Exploring the relationship between exposure to technological and gastrointestinal stress and probiotic functional properties of lactobacilli and bifidobacteria. Canadian Journal of Microbiology, 62(9), 715–725.
3. Arena, M. P., Caggianiello, G., Russo, P., Albenzio, M., Massa, S., Fiocco, D., Capozzi, V., & Spano, G. (2015). Functional starters for functional yogurt. Foods, 4(1), 15–33.
4. Balthazar, C. F., Silva, H. L. A., Esmerino, E. A., Rocha, R. S., Moraes, J., Carmo, M. A. V., Azevedo, L., Camps, I., K.D Abud, Y., Sant'Anna, C., Franco, R. M., Freitas, M. Q., Silva, M. C., Raices, R. S. L., Escher, G. B., Granato, D., Senaka Ranadheera, C., Nazarro, F., & Cruz, A. G. (2018). The addition of inulin and Lactobacillus casei 01 in sheep milk ice cream. Food Chemistry, 246, 464–472.
5. Bhatia, S., & Tandon, D. (2021). Nutritional, Therapeutic and Functional Aspects of Goat milk based Product fortified with Fruit Beverages. Advances in Nutrition & Food Science, 6(2), 4–16.
6. Bulgaru, V., Cușmenco, T., Macari, A., & ... (2020). Rheological and textural properties of goat's milk and mixture of goat's and cow's milk fruit yogurt. Journal of Engineering,
7. Chen, Y., Zhang, L., Hong, G., Huang, C., Qian, W., Bai, T., Song, J., Song, Y., & Hou, X. (2020). Probiotic mixtures with aerobic constituent promoted the recovery of multi-barriers in DSS-induced chronic colitis. Life Sciences, 240, 117089.
8. Coelho, M. C., Malcata, F. X., & Silva, C. C. G. (2022). Lactic Acid Bacteria in Raw-

Milk Cheeses: From Starter Cultures to Probiotic Functions. In Foods (Vol. 11, Issue 15).

9. Costa, M. P., Frasao, B. S., Silva, A. C. O., Freitas, M. Q., Franco, R. M., & Conte-Junior, C. A. (2015). Cupuassu (Theobroma grandiflorum) pulp, probiotic, and prebiotic: Influence on color, apparent viscosity, and texture of goat milk yogurts. Journal of Dairy Science, 98(9), 5995–6003.
10. Do Espírito Santo, A. P., Perego, P., Converti, A., & Oliveira, M. N. (2011). Influence of food matrices on probiotic viability - A review focusing on the fruity bases. Trends in Food Science and Technology, 22(7), 377–385.
11. El Hage, R., Hernandez-Sanabria, E., & Van de Wiele, T. (2017). Emerging trends in "smart probiotics": Functional consideration for the development of novel health and industrial applications. Frontiers in Microbiology, 8, 1–11.
12. Farag, M. A., El Hawary, E. A., & Elmassry, M. M. (2020). Rediscovering acidophilus milk, its quality characteristics, manufacturing methods, flavor chemistry and nutritional value. Critical Reviews in Food Science and Nutrition, 60(18), 3024–3041.
13. Fijan, S. (2014). Microorganisms with claimed probiotic properties: An overview of recent literature. International Journal of Environmental Research and Public Health, 11(5), 4745–4767.
14. Frakolaki, G., Giannou, V., Kekos, D., & Tzia, C. (2021). A review of the microencapsulation techniques for the incorporation of probiotic bacteria in functional foods. Critical Reviews in Food Science and Nutrition, 61(9), 1515–1536.
15. Furtado, D. N., Todorov, S. D., Landgraf, M., Destro, M. T., & Franco, B. D. G. M. (2015). Bacteriocinogenic Lactococcus lactis subsp. Lactis DF04Mi isolated from goat milk: Application in the control of Listeria monocytogenes in fresh Minas-type goat cheese.
16. Gamage, G., Adikari, A., Nayananjalie, W. A. D., Prasanna, P. H. P., Jayawardena, N., & Wathsala, R. (2016). Physicochemical, microbiological and sensory properties of Probiotic Drinking Yoghurt Developed With Goat Milk. 6(6), 203–208.
17. Gan, J., Kong, X., Wang, K., Chen, Y., Du, M., Xu, B., Xu, J., Wang, Z., Cheng, Y., & Yu, T. (2023). Effect of fermentation using different lactic acid bacteria strains on the nutrient components and mineral bioavailability of soybean yogurt alternative. Frontiers in Nutrition, 10, 1–12.
18. Ganesan, B., Weimer, B. C., Pinzon, J., Dao Kong, N., Rompato, G., Brothersen, C., & Mcmahon, D. J. (2014). Probiotic bacteria survive in Cheddar cheese and modify populations of other lactic acid bacteria. Journal of Applied Microbiology, 116(6), 1642–1656.
19. Giri, A., Rao, H. G. R., & Ramesh, V. (2013). Effect of incorporating whey protein concentrate into stevia-sweetened Kulfi on physicochemical and sensory properties. International Journal of Dairy Technology, 66(2), 286–290.
20. Guo, L., Van Hekken, D. L., Tomasula, P. M., Shieh, J., & Tunick, M. H. (2011). Effect of salt on the chemical, functional, and rheological properties of Queso Fresco during storage. International Dairy Journal, 21(5), 352–357.
21. Hernández-Ledesma, B., Ramos, M., & Gómez-Ruiz, J. Á. (2011). Bioactive components of ovine and caprine cheese whey. Small Ruminant Research, 101(1–3), 196–204. https://doi.org/10.1016/j.smallrumres.2011.09.040
22. Hill, C., Guarner, F., Reid, G., Gibson, G. R., Merenstein, D. J., Pot, B., Morelli, L., Canani, R. B., Flint, H. J., Salminen, S., Calder, P. C., & Sanders, M. E. (2014). Expert consensus document: The international scientific association for probiotics and prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nature Reviews Gastroenterology and Hepatology, 11(8), 506–514.

23. Islam, M. Z., Jahan, N., Liza, R. I., Sojib, M. S. I., Hasan, M. S., Ferdous, T., Islam, M. A., & Rashid, M. H. ur. (2022). Newly characterized Lactiplantibacillus plantarum strains isolated from raw goat milk as probiotic cultures with potent cholesterol-lowering activity. Journal of Agriculture and Food Research, 10, 100427.
24. King, S., Glanville, J., Sanders, M. E., Fitzgerald, A., & Varley, D. (2014). Effectiveness of probiotics on the duration of illness in healthy children and adults who develop common acute respiratory infectious conditions: A systematic review and meta-analysis. British Journal of Nutrition, 112(1), 41–54.
25. Kováčová, M., Výrostková, J., Dudriková, E., Zigo, F., Semjon, B., & Regecová, I. (2021). Assessment of quality and safety of farm level produced cheeses from sheep and goat milk. Applied Sciences (Switzerland), 11(7).
26. Kow, C. S., Ramachandram, D. S., & Hasan, S. S. (2022). Probiotics for the Prevention of COVID-19 Sequelae. Archives of Medical Research, 53(6), 643.
27. Kuley, E., Özyurt, G., Özogul, I., Boga, M., Akyol, I., Rocha, J. M., & Özogul, F. (2020). The role of selected lactic acid bacteria on organic acid accumulation during wet and spray-dried fish-based silages. Contributions to the winning combination of microbial food safety and environmental sustainability. Microorganisms, 8(2).
28. Liu, H., Xie, M., & Nie, S. (2020). Recent trends and applications of polysaccharides for microencapsulation of probiotics. Food Frontiers, 1(1), 45–59.
29. Londero, A., Hamet, M. F., De Antoni, G. L., Garrote, G. L., & Abraham, A. G. (2012). Kefir grains as a starter for whey fermentation at different temperatures: Chemical and microbiological characterisation. Journal of Dairy Research, 79(3), 262–271.
30. Maftei, N. M., Raileanu, C. R., Balta, A. A., Ambrose, L., Boev, M., Marin, D. B., & Lisa, E. L. (2024). The Potential Impact of Probiotics on Human Health: An Update on Their Health-Promoting Properties. Microorganisms, 12(2), 1–29.
31. Mandolesi, S., Naspetti, S., Arsenos, G., Caramelle-Holtz, E., Latvala, T., Martin-Collado, D., Orsini, S., Ozturk, E., & Zanoli, R. (2024). Consumer attitudes, motivations and barriers towards sheep and goat dairy products. International Journal of Gastronomy and Food Science, 36.
32. Melia, S., Juliyarsi, I., & Kurnia, Y. F. (2022). Physicochemical properties, sensory characteristics, and antioxidant activity of the goat milk yogurt probiotic Pediococcus acidilactici BK01 on the addition of red ginger (Zingiber officinale var. Rubrum rhizoma). Veterinary World, 15(3), 757–764.
33. Mituniewicz–Małek, A., Zielińska, D., & Ziarno, M. (2019). Probiotic monocultures in fermented goat milk beverages – sensory quality of final product. International Journal of Dairy Technology, 72(2), 240–247.
34. Mostashari, P., Marszałek, K., Aliyeva, A., & Mousavi Khaneghah, A. (2023). The Impact of Processing and Extraction Methods on the Allergenicity of Targeted Protein Quantification as Well as Bioactive Peptides Derived from Egg Molecules, 28(6).
35. Nayik, G. A., Jagdale, Y. D., Gaikwad, S. A., Devkatte, A. N., Dar, A. H., & Ansari, M. J. (2022). Nutritional Profile, Processing and Potential Products: A Comparative Review of Goat Milk. Dairy, 3(3), 622–647.
36. Nayik, G. A., Jagdale, Y. D., Gaikwad, S. A., Devkatte, A. N., Dar, A. H., Dezmirean, D. S., Bobis, O., Ranjha, M. M. A. N., Ansari, M. J., Hemeg, H. A., & Alotaibi, S. S. (2021). Recent Insights Into Processing Approaches and Potential Health Benefits of Goat Milk and It's Products: A Review. Frontiers in Nutrition, 8, 1–16.
37. Oliveira, T., Ramalhosa, E., Nunes, L., Pereira, J. A., Colla, E., & Pereira, E. L. (2017). Probiotic potential of indigenous yeasts isolated during the fermentation of table olives from Northeast of Portugal. Innovative Food Science and Emerging Technologies, 44, 167–172.

38. Papademas, P., & Bintsis, T. (2010). Food safety management systems (FSMS) in the dairy industry: A review. International Journal of Dairy Technology, 63(4), 489–503.
39. Park, Y.W., Haenlein, G.F.W., & Wendorff, W.L. (2017). Goat Milk – Chemistry and Nutrition. Handbook of Milk of Non-Bovine Mammals, Second Edition, 119, 42–83.
40. Parker, M. N., Lopetcharat, K., & Drake, M. A. (2018). Consumer acceptance of natural sweeteners in protein beverages. Journal of Dairy Science, 101(10), 8875–8889. https://doi.org/10.3168/jds.2018-14707
41. Paszczyk, B., Czarnowska-Kujawska, M., Klepacka, J., & Tońska, E. (2023). Health-Promoting Ingredients in Goat's Milk and Fermented Goat's Milk Drinks. Animals, 13(5), 1–16.
42. Popescu, L., Bulgaru, V., & Siminiuc, R. (2023). Effects of Lactose Hydrolysis and Milk Type on the Quality of Lactose-Free Yoghurt. Journal of Engineering Science, 29(4), 164–175.
43. Rai, D. C., Rathaur, A., Yadav, A. K., & Shraddha, M. (2022). Nutritional and nutraceutical properties of goat milk for human health: A review. Indian Journal of Dairy Science, 75(1), 1–10.
44. Ranadheera, C. S., Evans, C. A., Baines, S. K., Balthazar, C. F., Cruz, A. G., Esmerino, E. A., Freitas, M. Q., Pimentel, T. C., Wittwer, A. E., Naumovski, N., Graça, J. S., Sant'Ana, A. S., Ajlouni, S., & Vasiljevic, T. (2019). Probiotics in Goat Milk Products: Delivery Capacity and Ability to Improve Sensory Attributes. Comprehensive Reviews in Food Science and Food Safety, 18(4), 867–882.
45. Ranadheera, C. S., Naumovski, N., & Ajlouni, S. (2018). Non-bovine milk products as emerging probiotic carriers: Recent Developments and Innovations. Current Opinion in Food Science, 22, 109–114.
46. Ranadheera, C. S., Vidanarachchi, J. K., Rocha, R. S., Cruz, A. G., & Ajlouni, S. (2017). Probiotic delivery through fermentation: Dairy vs non-dairy beverages. Fermentation, 3(4), 1–17.
47. Rodrigues, F. J., Omura, M. H., Cedran, M. F., Dekker, R. F. H., Barbosa-Dekker, A. M., & Garcia, S. (2017). Effect of natural polymers on the survival of Lactobacillus casei encapsulated in alginate microspheres. Journal of Microencapsulation, 34(5), 431–439.
48. Sakandar, H. A., & Zhang, H. (2021). Trends in Probiotic(s)-Fermented milks and their in-vivo functionality: A review. Trends in Food Science and Technology, 110, 55–65.
49. Sari WK, Kristantri RS, W. D. (2021). Comparison of the Physical and Microbiological Characteristics of Peel-off Face Mask Yogurt from Fresh Cow's Milk and UHT Fermented Milk. Journal Eksakta, 22 04(04), 259–269.
50. Sharma, P., Bhardwaj, P., & Singh, R. (2016). Administration of lactobacillus casei and bifidobacterium bifidum ameliorated hyperglycemia, dyslipidemia, and oxidative stress in diabetic rats. International Journal of Preventive Medicine, 7(1), 102.
51. Sousa, Y. R. F., Medeiros, L. B., Manuela, M., Pintado, E., & Queiroga, R. C. R. E. (2019). Trends in Food Science & Technology Goat milk oligosaccharides : Composition , analytical methods and bioactive and nutritional properties. Trends in Food Science & Technology, 92, 152–161.
52. Tomotake, H., Okuyama, R., Katagiri, M., Fuzita, M., Yamato, M., & Ota, F. (2006). Comparison between Holstein cow's milk and Japanese-Saanen goat's milk in fatty acid composition, lipid digestibility and protein profile. Bioscience, Biotechnology and Biochemistry, 70(11), 2771–2774.
53. Tripathi, M. K., & Giri, S. K. (2014). Probiotic functional foods: Survival of probiotics during processing and storage. Journal of Functional Foods, 9(1), 225–241.
54. USDA FoodData Central (2019)

55. van der Toorn, M. V., Chatziioannou, A. C., Pellis, L., Haandrikman, A., van der Zee, L., & Dijkhuizen, L. (2023). Biological Relevance of Goat Milk Oligosaccharides to Infant Health. Journal of Agricultural and Food Chemistry, 71(38), 13935–13949.
56. Van Leeuwen, S. S., Te Poele, E. M., Chatziioannou, A. C., Benjamins, E., Haandrikman, A., & Dijkhuizen, L. (2020). Goat Milk Oligosaccharides: Their Diversity, Quantity, and Functional Properties in Comparison to Human Milk Oligosaccharides. Journal of Agricultural and Food Chemistry, 68(47), 13469–13485.
57. Verruck, S., Dantas, A., & Prudencio, E. S. (2019). Functionality of the components from goat's milk, recent advances for functional dairy products development and it's implications on human health. Journal of Functional Foods, 52, 243–257.
58. Wallace, C. J. K., & Milev, R. (2017). The effects of probiotics on depressive symptoms in humans: A systematic review. Annals of General Psychiatry, 16(1), 1–10.
59. Zenebe, T., Ahmed, N., Kabeta, T., & Kebede, G. (2014). Review on Medicinal and Nutritional Values of Goat Milk. Academic Journal of Nutrition, 3(3), 30–39.
60. Zhang, Y., Zheng, Z., Liu, C., & Liu, Y. (2020). Lipid Profiling and Microstructure Characteristics of Goat Milk Fat from Different Stages of Lactation. Journal of Agricultural and Food Chemistry, 68, 27.