




Review

Nutritional Profile, Processing and Potential Products: A Comparative Review of Goat Milk

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Abstract: Goat milk contains an abundance of different macro and micro-nutrients. Compared with other milk, goat milk is a viable option due to its low allergy levels and is preferred for infants with cow milk allergies. A wide variety of goat milk-based products, including yoghurt, ice cream, fermented milk, and cheese, are available on the market. They are produced using effective processing technology and are known to exhibit numerous health benefits after consumption. However, goat milk consumption is limited in many nations (compared with cow, buffalo, camel, and sheep milk) due to a lack of awareness of its nutritional composition and the significance of its different byproducts. This review provides a detailed explanation of the various macronutrients that may be present, with special attention paid to each component, its purpose, and the health benefits it offers. It also compares goat milk with milk from other species in terms of its superiority and nutritional content, as well as the types, production methods, health advantages, and other beneficial properties of the various goat milk products that are currently available on the market.

Keywords: goat milk; macro-nutrients; milk products; milk powder; nutritional value



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1. Introduction

In Mesopotamia (today's Middle East), goats were considered the first domesticated species as livestock around 8000 BC. Humans have utilized goats for various reasons across all continents for centuries. However, the goat sector has received less assistance globally than other animal production sectors, particularly the bovine milk sector, even though the goat has developed as a major livestock species in recent decades [1]. To a greater extent than any other farm animal, goats are a significant source of dairy and meat products for rural people in tropical and developing countries. Additionally, goats are often irreplaceable by other livestock and are acknowledged as a crucial economic component of farming because they can adapt well to a variety of climatic conditions. In addition, goats can consume forage and pasture that cattle do not. For these reasons, the adage “the goat is the poor man's cow” is accurate [2]. In underdeveloped nations, goat milk (GM) production is effective in combating malnutrition, particularly among infants [3]. Goat milk is becoming increasingly popular, not only to feed the poor and rural populations with small landholdings but also as a “super” dairy food with unique medicinal, nutritional, immunological, and biological properties [4,5].

Among the 1003 million goats across the globe in 2018–2019, 203 million were classified as dairy goats, producing 15.26 million tons of milk annually. Asia accounts for 52.7% of the total GM production worldwide, with India, Pakistan, and Bangladesh making a significant contribution. In 2017–2018, India produced 6.16 million tons of goat milk which is expected to increase to 8.2 million tons in 2022–2023 [6]. In India, the goat is commonly

referred to as the “poor man’s cow”, and it supports the dynamic growth of millions of people throughout the world. The Food Safety and Standards Authority of India (FSSAI) has issued regulatory standards for goat milk having a minimum of 3% milk fat (m/m), a minimum of 8% solid not fat (SNF) (m/m), and the total sodium content in the milk shall not be more than 650 mg/100 g SNF, emphasizing the significance of goat milk in the Indian dairy sector [6]. According to the Central Institute for Research on Goats (CIRG), goat milk production in India grew from 3.6 to 4.7 million tons, with a 2.6% annual rate of growth (as per the 2015–2016 report). As a result, India is considered on top in goat milk production, accounting for 29% of total production, respectively [7].

As a source of vitamins, proteins, and antioxidant macromolecules, goat milk is beneficial to people, particularly infants, as a substitute for cow milk (CM). From a nutritional standpoint, goat milk is notably different from milk from other dairy animals [8]. GM is more digestible than CM or human milk (HM), has a greater buffering capacity, and has specific therapeutic properties in human nutrition and medicine. GM has been suggested for individuals allergic to CM or different food sources [9]. By providing essential minerals and proteins, often to inhabitants of underdeveloped countries where CM is not readily available, GM has significantly contributed to human nutrition and their economic well-being [4,5]. Understanding the different functional properties of GM is important to develop different nutritionally enhanced GM products and specially to utilize GM formula as a nutrition source for infants and young children. Improved digestion, enhanced gastrointestinal function and gut microbiome population, greater absorption of minerals, desired food intake, low risk of allergy are the different functional properties exhibited by the consumption of GM [10].

GM can be processed into a range of products, including liquid milk products (fortified, low fat, or flavored), fermented products such as buttermilk, cheese, or yoghurt, and frozen products such as ice cream, condensed butter, and dry products. However, traditionally, cheese has been the primary GM product made and consumed in huge amounts worldwide [4]. However, goats have received highly negative press for a long time, resulting in widespread prejudice towards goat products offered in the United Kingdom (UK). It is considered that practically everyone who is not a goat admirer would characterize the milk as “rancid, salty, goaty, or sweet”. It was nearly impossible to get anyone to sample goat milk with such a negative reputation, even if it was supplied for free. Regrettably, this is true in many areas throughout the world. The public’s negative perception of the “goat-like” flavor and seasonal milk production are the two most significant barriers to marketing GM. The origins of this myth can be traced back to the fact that goat milk is occasionally obtained in unsanitary circumstances and that GM products are produced in substandard conditions. Only widespread education about goat milk’s health benefits and delicious taste can potentially change this negative reputation [2,11]. This review focuses on the significant macronutrients found in goat milk, a comparison of GM in various aspects with milk from other species, and detailed information on various GM products.

2. Macronutrients

Genetic, environmental, physiological, and handling variables are generally considered factors that influence goat milk composition [12]. Furthermore, due to the extensive and complicated genetic polymorphism of caseins present in goat milk, there is a considerable variation in content between animals within the same breed [13]. Nevertheless, goat milk generally consists of a good amount of significant macronutrients, including fat (4%), water (87%), carbohydrates (4.5%), protein (3.5%), and ash (1%) [14]. Table 1 demonstrates the average macronutrient composition (g) of goat milk.

2.1. Proteins

The most significant macronutrient in any goat species of milk is protein, which serves as a suitable benchmark for evaluating and analyzing the quality of nutrition in dairy products [15–17]. The amount of protein in milk varies depending on the breed,

species, lactation time, udder health, nutrition, and environmental conditions [5,18]. All casein (α S₁-, β -, α S₂-, and k-CN) account for 80% of milk protein, whereas whey protein (serum albumin, α -lactalbumin, β -lactoglobulin, immunoglobulins, proteose peptones, and lactoferrin) accounts for 20% [19]. Quantitative bioinformatics and proteomics have been utilized to verify the range of milk proteins through label-free quantification [20,21]. Casein has an isoelectric or isoionic point of 4.20 and its precipitation occurs at pH 4.20 at room temperature, but whey proteins remain soluble under the same conditions [5,13]. The different constituents of goat milk proteins and their compositions are given in (Table 2).

Table 1. Average macronutrient composition of GM. Source: [1].

Constituents	Concentration (g/kg)
Protein	27–35
Fat	30–40
Total solids	110–135
Lactose	41.0
Casein	25.0
Non-protein nitrogen	4.0
Albumin, globulin	7.0
Ash	8.0
Cholesterol	0.10
Energy	70.0 (Kcal/dL)

Table 2. The different components of proteins and their compositions found in goat milk.

Category	Constituents	Concentration	Unit	Reference
Major protein	α s-CN	26	(% of total casein)	[1]
	β -CN	64		
	k-CN	10		
	α s-CN/ β -CN	0.41 (ratio of %)		
	Lactoferrin	20–200	μ g/mL	
	Transferrin	20–200		
	Folate binding protein	12		
	Prolactin	44	ng/mL	
	Ribonuclease	425	μ g/dL	
	Lysozyme	25		
	Lipase	36	μ mol/dL	
	Malic dehydrogenase	50	μ mol/s per mL	
	Lactate dehydrogenase	47		
	Xanthine oxidase	19–113	μ L O ₂ /h	
	Alkaline phosphatase	11–13		
	Carnitine	16.4	mg/L	
	Orotic acid	13		
	Free amino acids	48		
	ATP	19		
	Sialic acid protease	13.89		

Table 2. Cont.

Category	Constituents	Concentration	Unit	Reference
Immunoglobulin	IgA	30–80	($\mu\text{g}/\text{mL}$) (milk)	[9]
		0.9–2.4	(mg/mL) (colostrum)	
	IgM	10–40	($\mu\text{g}/\text{mL}$) (milk)	
		1.6–5.2	(mg/mL) (colostrum)	
	IgG	100–400	($\mu\text{g}/\text{mL}$) (milk)	
		50–60	(mg/mL) (colostrum)	

Casein (CN) is among the most prevalent proteins in milk and is crucial for developing functional milk products [22]. During the lactation period, the casein content might vary [8,16]. The main distinguishing characteristics of major physical properties of GM are due to the presence of CN. Because of the importance of GM in the dairy global goat sector, more attention has been paid to this desirable food protein [23]. The production of effective infant formulae from goat milk contains a whey-to-casein protein ratio of 20:80 [10]. β -caseins are considered to be a crucial component of total GM casein, contributing 54.8% of total casein. When compared with other types of casein, more genetic variants are observed in β -casein and it is more complicated to differentiate them through gel electrophoresis. There is a total of four variants of β -casein (i.e., A, B, C, and D). Alkaline gel electrophoresis can help in differentiating the A variant from the B, C, and D variants, whereas acid gel electrophoresis differentiates the A variants from each other. The molar mass of the primary structure of β -CN is $23,980 \text{ g mol}^{-1}$ [9,24]. Now, considering another casein type—k-casein, it is the sole component of GM-CN, from which the determination of the entire amino acid sequence is carried out. The structure of k-casein consists of polymers mixtures together held by intermolecular disulfide bonds. A and B are considered to be two genetic variants of k-casein [9].

α -lactalbumins and β -lactoglobulins are considered to be significant types of WP. GM β -lactoglobulins consist of 162 amino acid residues formed by the polypeptide chain and are known to be different from CM β -lactoglobulins at six positions (including both terminal residues). CM and GM β -lactoglobulins are different in structures, where GM β -lactoglobulins are comparatively less stable than CM to denaturation by urea and both GM and CM β -lactoglobulins can be differentiated immunologically by the technique of microcomplement fixation. The different genetic variants of β -lactoglobulins (A, B, C, and D) originated from point mutations, and the differentiation among the genetic variants is due to the substitution of the amino acid at a different position [9]. α -lactalbumins is present predominantly in GM and other lactose-containing milk since it promotes in the biosynthesis of lactose at a faster rate. A and B are the two genetic variants of α -lactalbumins. The main component of α -lactalbumins contains four disulfide bonds and its amino acid sequence is comparable to lysozymes, where the 3-D model of α -lactalbumins is observed based on the coordinates of lysozymes isolated from egg white [9].

Humans can effectively digest lactose and beta-lactoglobulin (β -LG) present in GM as GM contains less concentration of lactose and αS_1 -CN. As a result, it is less allergenic than cow milk [16,25,26]. The composition of goat milk protein generally includes water-insoluble casein (70%), water-soluble whey protein (25%), and fat-soluble MFGM (milk fat globule membrane) protein (5%) [27]. The milk proteins are generally susceptible to precipitation and flocculation during the manufacturing and processing of different dairy products, which negatively influences the product quality derived from goat milk. As a result, alterations in goat milk proteins during processing are considered crucial [28]. As far as αS_2 -CN is considered the chief casein protein that belongs to the family of secretory calcium-binding phosphoprotein, αS_2 -CN generally comprises 223 amino acids and its molecular mass is 25.5 kDa when analyzed with chromatography [19]. It exists predominantly as a monomer, with intramolecular disulfide bonds maintaining its unique

tertiary structural shape. It makes up around 10–12.5% of the GM casein portion [29]. It has been shown that the high degree of polymorphism in the α S₂-CN genes found in goats significantly affects the concentration of α S₂-CN in GM [30]. The seven alleles associated with α S₂-CN of GM are A, B, C, D, E, F, and O. The O allele is related to an undetectable quantity of milk α S₂-CN and the D allele is linked with a decreased content of α S₂-casein [31,32]. Previous studies have shown that genetic polymorphisms impact goat milk's technological characteristics and composition [33–37]. A higher concentration of α S₂ casein present in GM provides better sites for interaction with k-carrageenan [38], which improves the firmness of the cheese texture [39,40].

B-lactoglobulin is resistant to pepsin activity in simulated gastric conditions; however, under intestinal conditions, milk proteins are completely hydrolyzed to small peptides and amino acids. In a research study, a human proteolytic enzyme was used to compare the *in vitro* digestion of GM and CM, and the results showed that GM digested comparably more quickly than CM. After the degradation of different protein profiles in GM and CM through the human proteolytic enzyme, a comparison was determined in different protein patterns through SDS-PAGE. A major difference was observed in the β -lactoglobulin. Through image analysis, when milk gel was treated with both human duodenal and human gastric juice, it showed that only a tiny portion (23%) of the β -lactoglobulin present in GM remained undigested. In contrast, a more significant portion (~83%) of the β -lactoglobulin present in CM remained undigested [41].

Lactoferrin, belonging to the family of transferrin proteins, is one of the standard glycoproteins found in goat and human milk [42,43]. Lactoferrin is involved in many biological functions, including antibacterial, antioxidant, iron (and other different metals) binding, antiviral properties, and immunomodulation [44–47]. In addition, the lactoferrin glycosylation and polypeptide chain modulate and influence its function [48]. Goat milk lactoferrin exhibits better coherence with the functional characteristics of human milk lactoferrin, making it a better choice for formula supplementation than the lactoferrin of cow milk [49]. Another class of whey protein is immunoglobulins, which are plasma cell-generated glycoproteins in mammalian milk that serve as antibodies in response to the immune system by binding to antigens, ultimately making them bioactive milk components. Immunoglobulins are essential for the newborn infant's immunity. Immunoglobulins present in GM are analogous to those found in the milk of sheep, cows, and colostrum. Immunoglobulins make up around 2% (generally between 1–4%) of whole milk proteins and about 12% (generally between 8–19%) of whey protein, respectively [50]. Transferrin is the name given to serum transferrin, as contrasted to lactoferrin, a milk component.

Understanding the interaction of WP and CN and the formation of the WP/CN complex is crucial in understanding the various production processes of different GM products. The interaction of WP with CN (majorly k-casein) occurs in GM when it is heated above 70 °C [51]. Recent studies have demonstrated that by heating the milk above 60–70 °C in oil/water baths or while using a plate heat exchanger (indirect) system, the denaturation of WP occurs at a temperature above 70 °C, resulting in its major association with the colloidal phase, probably forming of complexes with the k-casein at the surface of casein micelles. Apart from temperature, pH also affects the interaction between WP and CN. The interaction of denatured WP with casein micelles affected by pH was firstly observed from electron microstructural investigations, where images were taken of the heated milk samples, demonstrating that when the milk pH was less than 6.7 during heating at 90–140 °C/30 min, there was the formation of filamentous appendages by denatured WP on the surface of casein micelles, whereas at a higher pH the denatured WPs were found to be as serum-phase aggregates [52,53].

Morgan et al., [54] observed the role of the heat-induced interaction between casein micelles and WP in the heat stability of GM. It was suggested by the results that the interaction (heat-induced) between k-casein and β -lactoglobulin was not particularly significant at the natural milk pH, but was promoted at an increased pH. Pesic et al., [55] observed the k-casein and denatured WP distribution in micelle-bound and soluble complexes in

heat-treated CM and GM (90 °C for 10 min) at 6.71 pH (natural pH). The micelle-bound complex contained GM denatured WP (>95%), but soluble complexes were not seen. In contrast, soluble complexes containing around 30% of CM denatured WP were observed. In heat-treated CM, complexes containing around 24.2% of the total k-CN were produced; in heat-treated GM, this percentage is roughly three times greater. In addition to k-casein and WP, GM micelle-bound complexes contained β -casein and α_{s2} -casein, which were absent from their CM counterparts. This knowledge could be beneficial in understanding the functional and technological distinctions between GM and CM and improving control over dairy processes.

The complexes formed by WP/k-CN play a crucial role in numerous dairy processes such as the production of cheese, yoghurt, kefir, ice cream, UHT milk, skim milk powder, etc., and are known to positively or negatively affect production [55,56]. Considering the cheese production, the denaturation of WP and the formation of complexes result in longer rennet coagulation times, higher yields, and weaker structures of curd [57,58]. For UHT milk, the major factor influencing its lower shelf life is due to the gelation during its storage, which is exhibited by heat-induced protein interactions in milk [59]. The production of WP/k-CN complexes in heated milk during the production of yogurt results in higher firmness, improved viscosity, earlier onset of the process of gelation, and decreased acid gels syneresis [60,61]. The denaturation of WP and the formation of complexes are also responsible for determining the functional and technological features of skim milk powder and their appropriateness for different applications [62].

2.2. Fats

In terms of nutrition, cost, sensory, and physical qualities, fat content is considered by far the most variable milk compound, both qualitatively and quantitatively; it influences dairy products depending on the season, feeding, genotype, breed, and lactation stage [1]. The fat globules of smaller sizes, whose composition differs substantially from other milk types, are an essential component determining goat milk's superior absorption [63]. Tiny globules of fatty acids and more significant titers of short-chain fatty acids are generally observed in GM that are easily assimilated and digested [64,65]. Medium-chain fatty acids found in GM, such as caprylic, capric, and caproic acid, aid in the reduction of cholesterol by limiting its deposition and enhancing its mobilization in tissues [66]. GM triacylglycerols account for 98% of total fat, similar to other milk, with cholesterol, phospholipids, mono- and diacylglycerols, and free fatty acids accounting for the remaining 2% [67]. Caprylic, capric, and caproic fatty acids account for 15% to 18% of all fatty acids found in GM [68]. The short-chain fatty acid generally accounts for 15% to 18% of the fatty acid in goat milk. The distinctive "goaty" odor is partially due to medium- and short-chain fatty acids [13,69]. These are also essential for the ease with which milk fat is digested and absorbed, as there is more efficiency of the lipase enzyme on short chains than on long-chain fatty acids [3]. The size range of fat globules is around 1–10 μ m, and the fat globule ratio smaller than five μ m constitutes a more significant proportion (more than 80%) of GM [69]. The quantity of conjugated linoleic acid (CLA) and essential fatty acids in GM is also a significant variation in free fatty acids. Compared with other milk, GM contains higher essential fatty acids such as arachidonic, linoleic acid, and conjugated linoleic acid [3]. The different fat components and their composition present in goat milk are given in (Table 3).

GM fat contains a higher concentration of medium-chain triglycerides (MCTs), which are saturated fatty acids with 6–10 carbon chain lengths [70]. Long-chain triglycerides (LCT) and MCT were found to make up 53.95 and 30.83% of GM, respectively [71]. MCT is considered to be a highly accessible substrate of energy. Hence, it is believed that GM is digested more rapidly to create energy due to its high MCT concentration [72]. As a result, GM has a considerable energy-giving impact, particularly on growing youngsters [73,74]. The presence of branched-chain fatty acids (BCFAs) (originating from the hydrolysis of the bound form of fatty acid) in GM are further released as free fatty acids during milk processing, resulting in imparting a distinct "goaty" flavor to GM-based products (e.g.,

milk powder, yoghurt, or cheese) [75]. Greater concentrations of BCFA (both inbound and free form) have been observed in GM. All geometric and positional isomers of linoleic acid (C18:2) containing conjugated unsaturated double bonds are collectively referred to as CLA [5,76]. One of the biologically active CLA isomers, *cis*-9, *trans*-11-octadecadienoic acid, makes up more than 82% of all CLA isomers detected in milk products [9,76]. The largest concentrations of CLA and vaccenic acid (which is thought to be a physiological precursor of CLA) are typically found in milk fat [50]. Dairy goats grown exclusively on a pasture diet may produce milk with a higher CLA content [76].

The milk fat content of goats given more fodder showed greater levels of C6:0, C18:0, C4:0, C18:1, C20:0, C18:3, *iso*-, *ante-iso*-, and odd fatty acids, but lower levels of C12:0, C10:0, C16:0, C14:0, and C18:2 than goats fed less forage [77]. These dietary modifications might lead to an increase in the bioactive components in GM [50]. The milk fat globule membrane comprises the secretory cell's plasma membrane and contains proteins (including enzymes), cerebrosides, gangliosides, and phospholipids. The MFMG contains around 60% of the total phospholipids in goat milk. Their classes generally include sphingomyelin, phosphatidylethanolamine, phosphatidylinositol, phosphatidylcholine, and phosphatidylserine. A substantial amount of hydroxy acid precursor or aliphatic δ -lactones may be found in goat milk fat. These components are linked to the formation of flavors in dairy products that have been heated and stored [13].

The most energy-dense macronutrient by far is fat, which has a positive effect on human nutrition. Sadly, its excessive usage has been connected to several health issues [78]. Triglycerides, found in the fat globule, make up about 98–99% of milk fat. Minor fats make up the remaining 1–2%, including phospholipids (0.2–1.0%), diglycerides (0.3–1.6%), free fatty acids (0.1–0.4%), cerebrosides (0.01–0.07%), sterols (0.2–0.4%), and monoglycerides (0.002–0.1%) [50]. Phospholipids are an essential part of cell membranes in animal, human, and plant tissues. These biomolecules can work with ions, metabolites, hormones, antibodies, and various cells in an efficient manner. They are crucial for the normal functioning of cell membranes [79]. Polar lipids known as phospholipids make up about 1.6% of all lipids. A total of 16% of the entire polar lipid fraction is made up of glycolipids [80]. Quantitative analysis of GM revealed that the phospholipid fraction of bound lipids contained 35.4% phosphatidyl ethanolamine (PE), 4.0% phosphatidyl inositol (PI), 3.2% phosphatidyl serine (PS), 29.2% sphingomyelin (SP), and 28.2% phosphatidyl choline [50]. Among other minor lipids found in milk, gangliosides, glycosphingolipids, cerebrosides, glycolipids, etc., can be regarded as bioactive components. Even though these molecules are present in all mammalian tissues, very little research has been done on these minor lipids in GM. Goat milk cholesterol esters have more oleic and palmitic acid than cow milk cholesterol esters, according to fatty acid composition [5,81]. On average, goat milk fat globules are linked with 66% free cholesterol and 42% of esterified cholesterol [82]. The amount of cholesterol in goat milk differs substantially across breeds and a great proportion of it is present in the free state, with just a small percentage in the esterified form (52 mg/100 g fat) [50].

Table 3. Different components of fats and their compositions are present in GM.

Component	Key Components	Concentration (%)	Reference
Saturated fatty acid	Butyric (C4:0)	2.18	[83]
	Caproic (C6:0)	2.39	
	Caprylic (C8:0)	2.73	
	Capric (C10:0)	9.97	
	Lauric (C12:0)	4.99	
	Myristic (C14:0)	9.81	
	Palmitic (C16:0)	28.00	
	Stearic (C18:0)	8.88	
	Pentadecanoic (C15:0)	0.71	

Table 3. Cont.

Component	Key Components	Concentration (%)	Reference
Monounsaturated fatty acid	Myristoleic (C14:1)	0.18	
	Palmitoleic (C16:1)	1.59	
	Oleic (C18:1)	19.3	
Polyunsaturated fatty acid	Linoleic (C18:2)	3.19	[83]
	Linolenic (C18:3)	0.42	
	Linoleic conjugated (C18:2)	0.70	
Minor fatty acids	-	3.19	
Phospholipid fraction (%)	Phosphatidyl ethanolamine	35.4	[50]
	Phosphatidyl choline	28.2	
	Sphingomyelin	29.2	
	Phosphatidyl inositol	4.0	
	Phosphatidyl serine	3.2	

2.3. Carbohydrate

Oligosaccharides are generally characterized by the degree of polymerization and the carbon chain length and usually include around 3 to 15 monosaccharides, which are covalently linked by glycosidic linkages. The composition of milk oligosaccharides generally includes lactose, deoxyhexoses, N-acetyl hexosamines, hexoses, fucose, and neuraminic acid [84]. The structural classification of oligosaccharides is divided into acidic and neutral. Similarly, as other components are impacted by variables connected to the animal, these two fractions are also impacted by factors associated with the milk production and lactation of the animal. According to research, these factors can also cause variations in neutral and acidic oligosaccharides [85]. More recently, it was shown that genotype impacts changes in the goat milk profile of oligosaccharides, with animals of various genotypes having varied monomer concentrations in their milk [86].

Lactose (galactosyl- β -D-(1 \rightarrow 4)-glucose) is considered the most common and abundant carbohydrate found in goat milk, having a value of around 44 g L⁻¹ [87]. Lactose is the main component present in goat milk; nevertheless, it contains roughly 0.2–0.5 percent less lactose than CM [88]. Its concentration does not alter excessively. In contrast to cow milk, goat milk frequently has its lactose content significantly raised by dietary plant oil supplementation [89]. Somatic cell count (SCC) is still the simplest and most affordable way to record the health status of the mammary gland, even in goat breeding, even though several alternative indications of mammary gland subclinical infection have been proposed [90]. Additionally, lactose content can be utilized as a measure of the health of the mammary glands. Bagnicka et al., [91] studied the somatic cell score (SCS) and lactose content estimation of heritability and repeatability, as well as the genetic association between those and other dairy production traits. The milk of primiparous goats—goats that only had one kid—was found to have the highest lactose level. The SCS was lowest in the young goats. SCS and lactose content had heritabilities of 0.21 and 0.27 and repeatabilities of 0.31 and 0.55, respectively. Milk yield and lactose content had a genetic correlation of 0.46, while milk yield and SCS had a genetic correlation of 0.59. GM SSC and lactose content both appeared to be highly heritable. Therefore, integrating these characteristics in economic indices could improve animals' resistance to both clinical and subclinical mastitis [91]. Oligosaccharides, nucleotide sugars, glycoproteins, and glycopeptides are other carbohydrates found in minor quantities in goat milk [13].

The natural occurrence of oligosaccharides in goat colostrum has lately become the subject of research. Martin-Ortiz et al., evaluated the Murciano-Granadina goats' natural oligosaccharides present in their colostrum samples through quantitative and qualitative means. They identified overall 78 components as oligosaccharides, including neutral fucosylated, neutral non-fucosylated, and sialylated (Ne5Ac/Neu5Gc) oligosaccharides, having values of 3.8%, 51.3%, and 44.9%, respectively [92]. The most abundant

oligosaccharides discovered in goat milk were sialyl-lactoses, Hex-HexNAc-Neu5Gc, and Hex-HexNAc-Neu5Ac residues, having a neutral mass of 633.211, 690.232, and 674.238, respectively [86,93]. Goat milk oligosaccharides (COS), as previously described, contain complicated structures with varying glycosidic connections and degrees of polymerization (between two and seven) [86,94]. Neural COS is composed of monomeric units of galactose, glucose, fucose, and N-acetylgalactosamine (HexNAc) or N-acetylglucosamine connected to a lactose core. In contrast, acidic oligosaccharides are composed of these monomers plus N-glycolylneuraminic acid (Neu5Gc) or N-acetylneuraminic (Neu5Ac). These oligosaccharides found in GM are in greater concentration than in milk from other farm mammals, especially in goat colostrum, which is more common [85,92]. COS has lately been linked to a variety of bioactive characteristics, including significant prebiotic action [95], a decrease in intestinal inflammation [96], and enhancement of barrier function in co-cultures of epithelial cells [97]. Table 4 represents the different components of neutral and acidic oligosaccharide compositions found in goat milk.

The structural center of lactose is connected to glucose, galactose, fucose, N-acetylgalactosamine, and N-acetylglucosamine to produce neutral oligosaccharides. These components do not possess a charge in the monosaccharide residues [85]. The structural concentration and composition of neutral oligosaccharides differ among animal species because they are genetically determined. In comparison to human milk, milk samples from other species rarely connect with monomers of fucose. They are mostly N-acetylglucosamine or galactose, as indicated by the α -glycosidic bond at the non-reducing termini [86,98]. Lacto-N-hexose, 3-galactosyl-lactose, and N-acetylglucosamine-lactose are the three dominant neutral oligosaccharides present in goat milk [93]. Acidic oligosaccharides can react with other components and possess an electric charge when one or more have negatively charged residues of sialic acid [85]. In combination with the monomers that make up neural oligosaccharides, these molecules include residues of N-acetylneuraminic acid (NeuAc), commonly known as NANA, or sialic acid in their structures, and less often residues of N-glycolylneuraminic acid (NeuGc) [86]. Only NeuAc was detected in the oligosaccharides of human milk. At the same time, both NeuGc and NeuAc have been reported to be found in the milk of other animals (sheep, cattle, and goats), albeit in varying quantities [85,98].

Table 4. Major oligosaccharide components are present in goat milk. Source: [99].

Components	Key Components	Concentration (g L ⁻¹)
Acidic oligosaccharide	6-Sialyl-lactose	0.05–0.07
	3-Sialyl-lactose	0.03–0.05
	Disialyl-lactose	0.001–0.005
	N-glycolylneuraminyl-lactose	0.04–0.06
	Sialyl-Lacto-N-hexaose	Trace
	Sialyl-N-glycolylneuraminyl-lactose	Trace
	Sialyl-hexosyl-lactose	Trace
	N-glycolylneuraminyl-hexosyl-lactose	Trace
	Sialyl-N-glycolylneuraminyl-hexosyl-lactose	Trace
	Disialyl-hexosyl-lactose	Trace
	Di-N-glycolylneuraminyl-lactose	Trace
	Sialyl-dihexosyl-lactose	Trace
Di-N-glycolylneuraminyl-hexosyl-lactose	Trace	
Neutral oligosaccharide	3-Galactosyl-lactose	0.03–0.05
	Lacto-N-hexaose	0.001–0.005
	N-acetylglucosaminyl-lactose	0.02–0.04
	N-acetylglucosaminyl-Lacto-N-hexaose	Trace
	Di-N-acetylglucosaminyl-lactose	Trace
	N-acetylglucosaminyl-hexosyl-lactose	Trace
N-acetylglucosaminyl-dihexosyl-lactose	Trace	

3. Comparison of Goat Milk with Other Species' Milk

GM is now gaining more popularity as a potential alternative to products made from CM because of the potential nutritional benefits and the minor intense agricultural practices required to grow these animals [100]. For decades, GM has indeed been regarded as a source of nutraceuticals due to its simple digestion and lower allergic characteristics compared with CM [68]. GM, which is considered high in proteins, vitamins, and antioxidant molecules, is critical to the human population, particularly in infants, as an option to cow milk (CM). Goat milk differs substantially from milk from other dairy animals in terms of nutrients [9]. In comparison to CM or human milk (HM), GM is said to have different beneficial biological characteristics such as buffering capacity, higher digestibility, and some therapeutic benefits in human nutrition [50]. GM has lately acquired appeal among customers due to its reduced lactose level, high calcium concentration, high protein content, and a high proportion of better digestible fatty acids compared with CM [16,73,101].

According to the anecdotal literature evidence, goat milk has been utilized in the production of infant food (hypoallergenic) or milk substitute in infants suffering from CM allergy, as well as in patients affected by different allergies such as migraines, asthma, eczema, colitis, abdominal pain, epigastric distress, hay fever, chronic catarrh, and stomach ulcers due to the allergenicity produced by the protein of cow milk [73,102–104]. It was reported that the responsiveness or allergenicity of infants to CM but not to consumption of GM likewise responded the same to cheese produced from CM but not to cheese produced from GM [50]. GM is often the most similar to breast milk as a dairy product [105]. The fat granules present in GM are generally one-third the size of those in CM, making them more easily absorbed by the human body [106,107]. Aside from nutritional content, the flavor is essential for consumer acceptability and preference for milk products. Therefore, the flavor is considered an essential constituent in GM [108,109].

The Food and Drug Administration (FDA) and the Public Health Service define milk as containing the minimum nutritional value of fat and non-fat milk solids (addition of lactose, mineral content, and protein) as 3.25% and 8.25%. Even though the FDA guidelines were developed for cow milk, similar rules and definitions were applied to goat milk [110]. During a 5-month study, 38 children were fed with GM instead of CM. Increased weight, skeletal mineralization, height gain, and blood serum levels of riboflavin, calcium, hemoglobin, vitamin A, niacin, and thiamine were higher in GM-fed children than in CM-fed children. Similar results were observed when rats were fed with GM [73,111]. Over 20 years, French clinical investigations involving cow milk allergy patients revealed that substituting goat milk resulted in “undeniable” benefits. In a trial conducted in Madagascar, 30 hospitalized undernourished children aged one to five were given either CM or GM in addition to their usual diet. Thus, GM was suggested as an excellent alternative to CM for recovering malnourished youngsters [73]. GM contains somewhat less casein content but a higher concentration of non-protein nitrogen than CM. The protein and ash levels of GM, CM, and HM contain the most notable differences in the fundamental makeup [9]. The substantial differences in caloric values and total solids between CM, GM, and HM are not statistically significant [9,81]. The energy proportion obtained from protein and lactose is the most noticeable variation. Protein, fat, and lactose constitute roughly 25%, 50%, and 25% of the energy in CM and GM, respectively, whereas human milk contributes 7%, 55%, and 38%, respectively [81]. The comparison of GM in terms of nutritional content with other milk is described below.

3.1. Comparison by Protein Content

The primary distinction between cow and goat casein is the self-assembly of the proteins (amphiphilic) in aqueous solutions. In particular, casein is found in tiny micelles suspended in aqueous GM [112]. However, the β -casein present in cow milk possesses more solubility and the existing micelles are less solvated, small, and have less heat stability [73]. Because goat milk has relatively fewer caseins linked with a specified kind of α S₁-casein, it has lower allergenicity than CM [66]. Both CM and GM contain comparable amounts of k-

casein and α_2 -casein, with values ranging between 10–24% and 5–19% of total casein [113]. However, the β -casein is the predominant compound of GM and HM, accounting for ~60–70% and ~54.8% of total milk caseins, respectively, whereas α_1 -CN (regarded as primary protein) accounts for nearly 38% of total milk CN in CM. GM contains significantly less α_1 -CN than CM, contributing to 5.6% of total CN [110]. Except for sheep milk, the content of total whey proteins present in milk from diverse species (cow, human, and goat) is equivalent. There is a variation in the casein micelle sizes, as casein micelles of GM are relatively lower than 80 nm in diameter, while casein micelles of CM are 120 nm in diameter [3]. As a result, there was a considerably lower concentration of α_1 casein (which exists only in casein micelles) and a greater concentration of β -CN + κ -CN found in the serum phase. As a result, goat milk may be better absorbed in the human body than cow milk, which was one of the primary reasons GM is significantly superior in terms of nutritional utilization [114].

According to Park [104], the chief whey protein (WP) present in CM is lactoglobulin, which is not found in HM and is primarily accountable for CM allergy. Even though some goat milk proteins exhibited immunological cross-reactivity with proteins of cow milk, goat milk treatment has allegedly healed newborns with symptoms of CM allergy. Allergies exhibited by cow milk are responsible for exhibiting frequent illness, with a proportion of 2.5% in children throughout the first three years of life, appearing prevalently in 12–30% of infants, with an age of fewer than three months and as high as 20% in some regions [73]. The therapy with goat milk helped reduce these issues by 30–40% in those regions. In general, GM is recommended by doctors for children suffering from CM allergy [104,115]. It was discovered that an estimated 40% of all patients suffering from cow milk protein sensitivity also tolerate proteins from GM, making it beneficial for people affected by illnesses such as eczema, gallbladder diseases, digestive disorders, colitis, acidity, migraine, liver, asthma, stomach ulcers, and symptoms concerning stress such as insomnia, neurotic indigestion, and constipation [104]. These patients may resort to GM and its products to treat their disorders in the future [2].

Lactoferrin in GM contains 15 and 24 N-glycans, which are familiar with the N-glycomes of HM and CM, while all three species shared 13. Most of the high mannose N-glycans present were preserved among these species. Lactoferrin from human milk and goat milk had two N-glycans not seen in cow milk. This research demonstrated substantial lactoferrin N-glycan homology between GM and HM, indicating that GM might be utilized as a source of functional elements, including lactoferrin, beneficial for supplementation of infant formula [49]. Human milk (1–2 mg/mL) contains roughly ten times more lactoferrin than cow or goat milk (0.02–0.2 mg/mL), where lactoferrin is considered to be the chief iron-binding protein present in HM [49]. On the other hand, CM and GM have much higher transferrin levels than HM. The levels of transferrin and lactoferrin are virtually the same in milk from guinea pigs, goats, mice, cows, and sows, and it is predominantly present in rabbit and rat milk [116].

Proteome studies of GM revealed that several proteins were not detected in CM. These proteins are made up of peptide precursors implicated in the possible effect of hypotension (i.e., angiotensinogen), associated with the proper development of the mammary gland, and aid in immunological protection of the fetus (factor H). Therefore, they can be classified as defense factors (complement components C6 and C2) [117]. Davis et al., (1994) observed similarities in the general pattern of amino acids in the milk of all species studied in comparative research on the amino acid composition present in the milk of several species of primates compared with those of non-primates [118]. Glutamate (with 20% glutamine), leucine (10%), and proline (10%) were the most prevalent amino acids present. The HM's amino acid pattern was more identical to great apes than that of other non-primates or goats. Among the top three amino acids, non-primate and GM had more content of proline and glutamate and a comparatively lower concentration of leucine than animal milk [9,118].

3.2. Comparison by the Carbohydrate Content

Goat milk contains a surprising number of oligosaccharides, and the variety of oligosaccharides present in GM is significant. The oligosaccharides and monosaccharides are present at an optimal level in CM. Oligosaccharides present in milk have significant antigenic characteristics and help stimulate the growth of the newborn's intestinal flora. In addition, oligosaccharides increase the development of bifidobacteria in the neonate and function as pathogen-protecting intestinal mucosal cells. Finally, they may have a function in developing the neonatal brain. Goat milk has four times as much sialic acid (having a value of ~230 mg/kg of fresh milk) as cow milk (60 mg/kg of fresh milk). Furthermore, nucleotide sugars in the milk are essential since they are glycosyl givers for glycosyltransferase in the mammary gland and milk and precursors of glycolipids oligosaccharides glycoproteins in milk biosynthesis. GM has a relatively higher content of nucleotides ($154 \mu\text{mol } 100 \text{ mL}^{-1}$), followed by sheep milk, HM, and CM, having a value of $93 \mu\text{mol } 100 \text{ mL}^{-1}$, $68 \mu\text{mol } 100 \text{ mL}^{-1}$, and $5 \mu\text{mol } 100 \text{ mL}^{-1}$ [13].

In comparison to sheep and cows, the oligosaccharides present in GM are more comparable to those found in HM; hence, GM can be regarded as a natural oligosaccharide source for infants [69]. According to studies, goat milk contains more sialyloligosaccharides and fucosylated oligosaccharides than milk from other ruminants [86,87]. (Kiskini and Difilippo, 2013) [119] showed in a recent study that six oligosaccharides ($\beta 3'$ -galactosyllactose, $2'$ -fucosyllactose, $\beta 6'$ -galactosyllactose, $3'$ -N-acetylneuraminyllactose, lacto-N-hexaose, and 6-N-acetylneuraminyllactose) were identified in GM and are likewise present in HM. The lacto-N-biose unit (considered the building block of type I human oligosaccharides) has been detected in the GM oligosaccharides. A total of 40 oligosaccharides were identified in goat milk, with a varied concentration ranging between 250 and 300 mg L⁻¹ [99], which is considerably less than that of HM, about four times that of CM, and nearly ten times that of sheep milk [119–121].

The presence of neutral structures such as lacto-N-hexaose and galactosyl-lactose and sialylated structures such as disialyl-lactose and 3-6-sialyl-lactose in GM and breast milk oligosaccharides, explains the similarities between both milk oligosaccharides [99]. Although the oligosaccharide content in GM is relatively less than in HM (0.25–0.30 g/L), it is significant higher than in sheep milk and CM, having values of 0.02–0.04 g/L and 0.03–0.06 g/L, respectively [99,119,122].

3.3. Comparison by Fat Content

The physicochemical structure and concentration of milk fats vary significantly between CM and GM. The GM has an average fat globule size of around 3.5 μm , but cow milk fat globules are 4.5 μm [9,15,123]. The average fat globule diameter was observed in cow milk (4.55 μm), goat milk (3.49 μm), buffalo milk (5.92 μm), and sheep milk (3.30 μm), respectively [9]. The fat globules possessing a smaller size resulted in improved dispersion and a more homogenous fat combination in GM, providing lipases with a larger surface area of fat for improved digestive activity. From the standpoint of human health, GM homogenization by natural means would be considered healthier for digestion than CM products prepared by mechanical homogenization [9,124]. A research study demonstrated that the size of goat milk fat globules (3.2 μm) was relatively larger than camel's milk (2.99 μm). This variation in fat content in GM leads to improved digestion for humans, a relatively more effective lipid metabolism, and the providence of a soft texture for products made from GM [69,74,104]. Another distinction between goat milk fat and other animals' milk is its creaming capability. The creaming potential of GM is relatively weak due to the reduced fat globule size and the lack of agglutinin compared with the milk of other species, particularly at lower temperatures [81]. The size of fat globules was reduced in the sequence buffalo > cow > goat > camel, whereas the digestibility of fat improved in the order buffalo < cow < goat < camel. The fat obtained from camel milk and GM had the maximum fat digestibility because of their small fat globule size. After fat digestion,

there was no observation of a substantial difference between them for the release of fatty acids [78].

There is a substantial variation in free fatty acids concerning the concentration of essential fatty acids (EFAs) and conjugated linoleic acids (CLAs) in GM. Compared with other milk, GM contains more CLAs and EFAs (such as arachidonic and linoleic acids), which are considered the geometric and positional isomers of linoleic acid [13,125]. Quantitative and qualitative profiles for primary branched-chain free fatty acids were identified in sheep milk, CM, and GM, except for 4-methyl octanoic acid, which was detected in cheese produced from cow milk [126]. Cow milk fat contains optimal levels of 4-methyl octanoic acid. However, goat and sheep milk fat included considerable concentrations of 4-ethyloctanoic acids and 4-methyloctanoic acids, producing goat-like and mutton-like flavors, respectively [126]. The substitution of GM for CM resulted in a considerably better absorption rate of intestinal fat in an Algerian trial performed on 64 infants suffering from malabsorption disorders [73].

The mean cholesterol concentration present in HM, CM, and GM was reported to be 14, 14, and 11 mg/100 g of milk, respectively [50], suggesting that GM has less cholesterol content than other milk. However, GM contains more total fat than CM (in March, April, and December) [127]. A higher concentration of cholesterol results in a greater risk of coronary heart disease. Hence, GM's relatively lower cholesterol level may be beneficial for human health and nutrition [81]. As with cow milk, GM's significant proportion of cholesterol is in free form, with a small fraction in esterified forms, 52 mg/100 g fat, accounting for less than 4% of total cholesterol [9,81]. The composition of fatty acids involving cholesterol esters shows that esters present in goat cholesterol include more oleic and palmitic acid components than cow cholesterol esters [9,81]. The unsaponifiable matter concentration in GM is 46 mg/100 g fat or 24 mg/100 mL, equivalent to CM. The majority of this milk lipid fraction (91%) is cholesterol, with a fat content of 420 mg/100 g [9].

3.4. Comparison by Vitamins and Minerals Content

In terms of mineral content, GM is reasonably comparable to CM in terms of Na, Zn, Mb, and Fe but has more Ca, Cl, Mg, K, P, and Mn [114]. The mineral content of GM differs due to diet, stage of lactation, genetics, and analytical procedures [13]. Several studies have reported that GM possesses higher magnesium, calcium, copper, iron, and phosphorus bioavailability than cow milk [128]. GM's nutritionally essential P_2O_5 /CaO ratio is more comparable to HM than that of CM [129]. The principal mineral concentrations in milk from various goats are relatively consistent. However, the content of trace elements may be influenced by breed, lactation stage, individual variations in animals, and diet [130]. Goat milk comprises around 134 mg of calcium and 121 mg of phosphorus per 100 g of milk. It means only one-sixth to one-fourth of these minerals are found in HM [9].

Zinc has the highest trace mineral concentration of any trace mineral, and Zn levels in CM and GM are more significant than in HM [131]. The iron concentration in CM and GM is much lower than in HM. On the other hand, CM and GM have considerably higher quantities of iodine than HM, which is considered essential for human nutrition since thyroid and iodine hormones are directly connected to the metabolic rate of various physiological processes occurring in the human body [9]. The selenium contents of HM and GM are higher than that of CM. Glutathione peroxidase levels in GM were more outstanding than in HM or CM. The activity of total peroxidase (related to glutathione peroxidase) in GM was 65%, compared with HM (29%) and CM (27%) [132]. The average molybdenum (Mo) composition in CM and GM is 25.9 and 12.4 $\mu\text{g/L}$, respectively. A goat's diet supplemented with 1.1 mg of Mo per day generated 12 $\mu\text{g/L}$ of Mo in milk, whereas 13.0 mg of Mo/day increased Mo in milk to around 70 $\mu\text{g/L}$. The borate level in goat, human, and cow milk was likewise reported to be 2.6, 0.42, and 1.1–2.2 mg/L, respectively [9,81].

Goat milk was reported to contain a considerably more significant concentration of vitamin A than CM because goats convert all carotenes into vitamin A and are typically

whiter in color than CM [13,83]. GM is similarly high in concentration of niacin, riboflavin, thiamine, and pantothenate [3], but is considered a poorer source of folic acid and vitamin B12, with just 20% of the folic acid concentration of CM and comparatively less bioavailability than HM and CM. In addition, vitamins B6, C, and D are relatively lower in both cow and goat milk, where these vitamins are generally supplemented from different sources (e.g., food) [68].

4. Influence of Milking Parlors on Goat Milk

Milking parlors present on goat farms play an important role in improving the quality and overall yield. The neuroendocrine milk ejection reflex in goats is different from a dairy cow because of the larger milk storage capacity in the gland cistern [69], which implies that natural suckling has less potential to increase milk supply than machine milking. However, it has been noted that the performance of dairy goats that are naturally suckled versus those that are machine milked varies significantly depending on the production or experimental conditions. Goats are typically milked twice daily, however, there is growing interest in switching to once-a-day milking to cut labor costs. When compared with milking twice daily, the reduction is typically in the range of 20%. However, the magnitude of the effect of milking frequency on milk yield varies with a variety of factors, one of which is breed, with less impact for goats with low vs. high production potential and low vs. high diet quality [133]. Similarly, when yield is higher in mid and early lactation than in late lactation, the effect of milking frequency is stronger [69]. Tormo et al., [134] studied the identification of the major lactic acid bacteria present in raw GM from three distinct areas in France and determined whether specific farming methods have an impact on how different species of lactic acid bacteria are distributed in the milk samples. The geographical area under investigation was associated with the prevalence of *L. lactis* subsp. *cremoris*. It seems that the habitat of the animals affects the population of *L. lactis* and enterococci predominate in raw GM. It appears that *L. lactis* in the milk (as opposed to enterococci) is promoted by the separation between the milking parlor and the goat shed and by the use of only straw in the bedding (as opposed to straw and hay). This would ultimately help to improve the sensory and technological aspects of lactic cheeses.

5. GM Based Products

There is little information on the production of different GM products such as liquid (reduced fat, flavored, or fortified milk), cultured (yoghurt or buttermilk), and frozen products (condensed milk, ice cream, and dried milk) [73,115]. There is a research gap in GM that has to be filled. However, some recent studies on products produced from goat milk have been published [110,135]. There are few publications on GM products, most likely because of the considerably more significant volume of CM, making it more appropriate for efficient commercial interest than GM [136]. Goat milk may be utilized to make various products, including cultured, fluid, dehydrated, and frozen items. Milk composition standardization, particularly of fat content, is required to ensure the legality and consistency of the completed product [110]. Around the world, there are many varieties of liquid GM. Some nations have more commercialized whole milk, whilst others desire skim milk. Some nations have legislation for the incorporation of vitamins. Another difference is the package size, ranging from 454 g to 3.6 L for home use. Packaging is available in various materials, including paper cartons, plastic, and glass. The product's shelf life varies according to the type of packaging, processing, and specific legislation [2].

The positive impact of some varieties of functional foods and a particular part of their components have been researched to enhance the health of consumers [137]. Thus, functional foods are those that provide health advantages in addition to essential nourishment [137]. One of the global research goals is to explain the characteristics of foods with functional claims [138]. In this respect, products produced from goat milk with these qualities might help the business to improve by introducing new goods and increasing customer demand [139]. Foods with functional claims contain probiotic microorganisms

or prebiotic components. Goat milk has numerous properties that benefit human health, including high buffering and digestibility capacity, decreased cholesterol levels, lower allergenic potential compared to CM, and a high calcium content [140]. These qualities also enable the production of a wide range of dairy products from GM, including non-fermented and fermented dairy beverages, cheese, yoghurt, ice cream, butter, condensed milk, and sweets. Additionally, the addition of probiotics—living bacteria that provide benefits to the body when taken in appropriate amounts—might increase the functional value of GM [83].

GM is a multicomponent colloidal system that has good techno-functional properties. GM protein plays an important role in the formulation of different dairy products and contributes to their final texture and appearance. The presence of a relatively lower amount of α_{s1} -casein in GM results in the production of softer gel products, a lower viscosity, and greater water holding capacity [141]. Gursel et al., [142] studied the manufacturing of GM yogurt with 2% (weight/volume) fortification of each of sodium caseinate, skim GM powder, whey protein isolate, and whey protein concentrate. Yogurt made with sodium caseinate resulted in greater acceptance among all the other yogurts. The higher syneresis value was observed in yogurt made from whey protein isolate because it produces the hardest texture. Apart from skim GM powder, all other yogurt variants possess lower acidity values and a comparatively higher protein content.

The enhancement of the manufacturing quality of GM should initially begin at the farm level since the milk quality and flavor cannot be enhanced at the later processing stage [110]. Moreover, milk deteriorates quickly because it is a nutritious substrate for bacterial development. Therefore, a cleaner environment for milking is just as vital as the content of the milk and the higher the quality of raw milk, the higher the quality of the processed products observed [11].

5.1. Yoghurt

Yoghurt, a fermented type of dairy product, is a healthy food that can provide consumers with various health advantages [143]. Traditional adjunct and yoghurt cultures that are frequently introduced for their health advantages have been the subject of research into the potential health benefits of yoghurt. Yoghurt and probiotics have been linked to various health advantages, including decreased blood cholesterol, immune system stimulation, a lowered rate of lactose intolerance, a lower risk of colon cancer, better digestive regularity, enhanced calcium absorption, and normalization of intestinal microbiota [144]. Manufacturing of fermented products, specifically yoghurt made from GM, is typically regarded as difficult because it has identical coagulation and consistency characteristics to that of cow milk products, owing to the presence of low natural α_{s1} -CN content and periodic changes in the composition of GM. Various methods, such as the incorporation of stabilizers, the utilization of specific starter and probiotic cultures that aid in producing exopolysaccharides, increasing the solid content of milk, processing of milk with transglutaminase, and homogenization of enzymes by utilization of high-pressure, may allow the manufacturing of yoghurts (probiotic fortified) from GM with acceptable rheological and consistency characteristics [145].

One of the primary causes of the poorer acceptance of particular GM products compared with comparable products manufactured with CM is the potential unfamiliarity of consumers with GM. A sensory panel consisting of 17 males (having a mean age of 44.5 ± 15.2 years) and 28 females (having a mean age of 48.3 ± 13.6 years) was repeatedly provided with GM yoghurt supplemented with probiotic *L. acidophilus*. It was discovered that taking both the yoghurt for six days in a row improved the acceptance rate of GM yoghurt, thus suggesting that increasing such exposure sessions to different consumers may increase the acceptance rate of products made from goat milk [146]. Research conducted on goat milk yoghurt reported that the addition of polymerized WP may reduce the syneresis of yoghurt. They discovered that soluble aggregates of whey protein could bind to the casein micelle surface, which encouraged the development of bridges between molecules of casein, resulting in a relatively less porous casein/heat-induced network

of whey protein [147]. Moschopoulou et al., (2018) investigated the semi-skimmed and skimmed yoghurt syneresis of sheep milk, as well as semi-skimmed GM and CM yoghurts. Their findings revealed that yoghurt prepared from GM had the maximum water holding capacity (WHC). Despite this well-known trait, researchers are constantly striving to enhance viscosity and texture characteristics [148].

An enzymatic technique based on microbial transglutaminase (MTGase) has been created to modify and enhance the texture of yoghurt. The University of Vermont recently created a probiotic yoghurt (texture-improved) produced from GM by utilizing enzymatic cross-linking [11,110]. The addition of MTGase considerably enhanced the yoghurt consistency. Scanning electron micrographs indicated that when the MTGase level was improved from zero to two and four units per gram of protein, the yoghurt's microstructure treated with MTGase became thicker [110].

5.2. Cheese

The link between cheese quality and milk quality is widely known and numerous good studies on the effects of GM qualities on cheese quality and cheese production have lately been published [149]. Cheese produced from goat milk is gaining more popularity than other goat milk products worldwide. The prominent flavor components in cheese are produced by the metabolism of amino acids (methional, 3-methylbutanal, dimethylsulfide, and methanethiol), fats (acetic acid and butyric acid), sugars (2, 3-butanedione, and diacetyl), and other components such as limonene, which can be produced via a variety of pathways [150]. The manufacture of numerous varieties of raw GM cheeses without the utilization of commercial starter cultures is standard [151] and these cheeses are consumed by a sizable population [152].

The goat milk industry has achieved economic significance and global recognition because of its use in the cheese business in Eastern European and Mediterranean countries. Cheese is perhaps the most significant GM dairy product, with around 400 GM cheese variants and 800 variants from an admixture of cow, goat, ewe, and buffalo milk documented in the United States Department of Agriculture's Agricultural Handbook No. 54. (USDA) [11]. A more excellent content of dry matter (protein, fat, and lactose) is connected with more outstanding quality and a milder taste of milk for cheese production. The quality of coagulation and taste are significant characteristics that influence cheese quality and yield. The dry matter content is connected to the amount of cheese produced favorably [153]. The removal of whey is a crucial step in concentrating other milk components during cheese production. Ultrafiltration (UF) was found as a potential technology for concentrating skim milk before the addition of rennet and producing cheese with low moisture content without changing the nutritional characteristics owing to heat treatment [154].

The milk was most likely turned into soft cheese and, eventually, hard matured GM cheeses were produced in the Mediterranean basin nations [155]. Many nations restrict the production of raw goat milk cheese owing to food safety concerns (brucellosis). The type of milk utilized has a significant impact on the final cheese [156]. Many distinct elements influence the ripening or maturation of cheeses made from goat milk [157].

Furthermore, production processes vary significantly in terms of the number and species of organisms involved in the procedures of incubation, culture, incubation, and pressing or shaping techniques. The variation in maturing time and circumstances is essential in influencing the cheese's taste, body, and texture. Most goat cheeses are manufactured using delayed coagulation, which means curd that remains with whey until dipped into molds and dried before ripening. The wide variety of cheese variants manufactured from goat milk has contributed to the development of a wide range of products [2]. The natural lactic bacteria found in raw GM used to make cheese may play an essential role in creating cheese. Throughout the ripening of this white brined type of cheese, relatively high counts of lactic acid bacteria, anaerobic bacteria, lipolytic and proteolytic, and psychrotrophic bacteria were detected [158]. *Lactobacillus plantarum*, *Enterococcus durans*, and *Leuconostoc paramesenteroides* were the most common lactic acid bacteria recovered from raw GM [1].

Gjetost cheese from Norway is prepared from the whey of GM, where lactose (caramelized form) in concentrated whey is mixed with whey proteins and fat [2]. Ricotta is another famous Italian cheese prepared from the whey of goat milk. Labaneh, a classic fresh cheese, is highly popular in Middle Eastern nations [1].

The completeness of the raw GM pasteurization process is confirmed by the action of raw milk enzymes (naturally occurring) such as γ -glutamylotransferase or lactoperoxidase, and alkaline phosphate (ALP) [159]. The European Union legislation has defined a safe level of ALP activity as 350 mU/L for CM consumption and it is detected through fluorimetric determination as a reference method. However, the limits have not yet been determined for milk and cheeses from animals other than cows. The European Union Reference Laboratory for milk and milk products has proposed a provisional limit for pasteurized GM that is equal to cow milk (350 mU/L) and a 10 mU/g limit for cheeses made from pasteurized milk [159]. The cheese is often produced on smaller farms using raw GM however, pasteurized milk might be used to standardize the raw milk's processing behavior and to produce a cheese of consistent quality that satisfies the current microbiological safety requirements [160]. Pappa et al., [160] studied Xinotyri cheese made using pasteurized or raw GM without using the starter cultures, and the biochemical and microbiological characteristics changes were examined during storage and ripening. Pasteurization of GM affected the fat, protein, moisture, ash, total free fatty acids, total free amino acids content, and nitrogen fractions of cheeses. In contrast to pasteurized milk cheeses, primary proteolysis, which could be seen on urea-PAGE, was more pronounced in raw milk cheeses. However, the proportion of hydrophilic and hydrophobic peptides in the water-soluble fraction was comparable in the two cheeses. Based on the analyzed biochemical features, cheeses could be distinguished clearly based on the kind of milk (raw, pasteurized), as well as the stage of ripening. According to Tadjine et al., [161], assessing the pasteurization effect on the yield of GM and CM cheese reveals that using pasteurized milk enhances the yield through an improved moisture content of the cheese. Additionally, GM yields more cheese than CM and has a higher fat and protein content.

5.3. Fermented Milk

Since 5000 BC, fermented milk and drinks have been discussed regarding their health and nutritional benefits. Fermentation, as a process, is the conversion of primary raw materials into a variety of value-added products by using the phenomena of microbe growth or their activity on milk [2]. In human subjects, live lactic acid bacteria present in fermented milk products have been linked to enhanced lactose tolerance, antibacterial activity, a well-balanced intestinal microbiota, anticholesterolemic, immune system activation, antitumoral, and antioxidative characteristics [162–164]. Furthermore, fermented GM loses its distinctive “goaty” flavor that is unpalatable to many people [73]. To increase the sensory acceptability of fermented GM, probiotic microorganisms were used. Uysal-Pala et al., (2006) assessed the sensory qualities of fermented GM produced with probiotics (*Bifidum* BB-12 and *Lactobacillus acidophilus* LA-5) and regular (YO-FLEX YC-350(Y)) cultures [165]. The samples of fermented milk probiotic-enriched with (*L. casei* ATCC 393), produced from goat milk, and those made using a mix of CM and GM, have been shown to have a higher rating of sensorial quality than equivalent fermented milk samples manufactured exclusively from CM [166]. Furthermore, Probiotic *L. rhamnosus* CRL1505 has been utilized in the fermentation of GM. In this trial, the product was approved by 90.48 percent of consumers (84 participants aged 6–15 years) and was judged to have a wrong impression and an appealing odor [167].

The application of strawberry juice to fermented goat milk during the pre-fermentation process might improve the physicochemical characteristics compared with samples containing juice added during post-fermentation. Regarding the volatile ratio, the goaty taste and fruit profiles of fermented milk before fermentation were significantly lower and higher, respectively, than those of fermented milk after fermentation. According to Wang et al., 2019, adding strawberry juice pre-fermentation may be a promising technology, and strawberries

may be a suitable approach for creating fermented flavored goat milk [168]. *Lactobacillus acidophilus*, which can convert a higher proportion of lactose to lactic acid, can produce acidophilus milk. It is considered low-fat or pasteurized milk injected with *Lactobacillus acidophilus*, which kills other competing bacteria in the lower intestine that are hostile to man. These organisms can colonize the big intestine, withstand the low surface tension, and shift nutrition [110].

Kefir is a fermented milk product that is generally foamy and acidic, prepared from fat-standardized and pasteurized or decreased goat milk after a combined alcoholic and acidic fermentation of yeast “kefir grains” and symbiotic lactic acid bacteria [110]. Kefir includes alcohol (0.5–1.0%), lactic acid (0.6–0.8%), and carbon dioxide, respectively. *Saccharomyces kefir*, *Lactobacillus caucasicus*, *Leuconostoc* spp., *Torula kefir*, and lactic acid streptococci dominate the microbial flora of kefir. Yeasts make up around 5 to 10% of the total population of microbes [110]. Kefir made from GM, CM, and sheep milk with commercial starter culture or grain inoculation had identical microbiological properties during storage, with yeast, lactococci, and lactobacilli as the major microorganisms, and a higher ethanol concentration in kefir made from commercial cultures. On day 15, the ethanol concentrations were found to be in goat (1.46%), sheep (1.4%), and cow (2.1%) milk kefir, respectively [169]. The kefir produced from GM and CM had a relatively different composition of organic acids, with goat milk kefir having greater malic and lactic acid concentrations, while cow milk kefir having greater concentrations of acetic, oxalic, succinic, and citric acids [170]. Another buttermilk product is generally prepared from skim milk by making butter from sour cream. GM buttermilk is usually created from skim milk (consisting of less than 0.5% fat) [110].

5.4. Ice Cream

Ice cream manufactured from GM is considered an appealing choice for consumers and children because of its nutritious and anti-allergenic characteristics and its creamy organoleptic features. The manufacturing of ice cream from goat milk is generally flavored. The most popular flavors are chocolate, vanilla, and premium white chocolate mix [2]. A study evaluated the physical, chemical, and organoleptic characteristics of ice cream manufactured from GM, sheep milk, and CM for their appropriateness for manufacturing ice cream. The most acceptable ice cream was made using goat milk, followed by cow milk [2,136]. It was concluded that GM ice cream has a smoother texture and unique melting properties [2]. The production of GM ice cream by using probiotic bacteria is more challenging than making fermented cheese and milk, because probiotic bacteria cannot sustain their viability in frozen products. The formation of acidity and homogenization during the mixing of ingredients and damage induced by freezing are responsible for reducing the viability of these probiotic bacteria [171,172]. However, several new technologies for producing ice cream with good probiotic microorganisms are now available [173].

The three flavor formulations of ice cream made from goat milk are: (i) French vanilla mix consisting of fat (14%), sweetener (18%) (containing 36 dextrose identical corn syrup solids (6%) and sucrose (12%)), MNSF (10%), stabilizer ± emulsifier (0.25%), and egg yolk solids (1.4%); (ii) chocolate mix consisting of fat (14.6%), sweetener (20%) (containing 36 DE corn syrup solids (6%) and sucrose (14%)), MSNF (9%), stabilizer ± emulsifier (0.22%), and medium-fat cocoa (3%); (iii) premium white mix consisting of fat (10%), sweetener (18%), MSNF (10%), and stabilizer ± emulsifier (0.25%) [110]. A chocolate-flavored goat-milk ice cream containing probiotic bacteria ice cream was created using a method identical to that used to make cow-milk ice cream by utilizing *L. acidophilus* LA-5, *B. animalis* subsp. *lactis* BB-12, and *P. jensenii* 702 [174]. The storage of the product was studied for up to 52 weeks at a temperature of -20°C and it was kept in polypropylene, polyethylene, and glass packing materials. The product was evaluated using a 9-point hedonic scale. The sensory evaluations of qualities such as color, appearance, aroma, texture, body, taste, and melting properties were extremely satisfying, ranging from ~6 to 7. The commonly stated disagreeable “goaty” flavor was rarely detected, according to the findings. However, the type of material used for ice cream packing significantly impacted the time necessary for the

ice cream to melt. The packing materials had no effect on the other chemical characteristics and sensory qualities assessed. Nonetheless, after 12 weeks of storage, the product's characteristics such as flavor, texture, and body changed. Then, no negative effects were linked with frozen storage and, in fact, extended storage durations somewhat improved several sensory properties of probiotic GM ice cream [174].

5.5. Powder and Condensed Milk

As previously noted, GM powder or evaporated GM is suggested for utilization as a formula for infants because the heat in the production process decreases allergenicity [1]. Powdered products generally include whole milk and skim milk powder, infant foods, and whey powders [1]. There is little literature on the manufacturing of powdered GM, probably due to the scarcity of significant volumes of GM from low-output farms [136]. Kruger et al., (2008) [175] found that the powder of GM, when combined with probiotics and prebiotics, increased the retention and absorption of minerals in human digestion. Evaporated GM (condensed), usually unsweetened or sweetened, is often produced under decreased pressure, allowing for boiling at a lower temperature and avoiding heat damage [2]. Dried milk powder from GM may be produced in three ways [136]: roller drying, spray drying, and freeze drying. Pulverization and spray drying are the techniques used in Brazil. The pulverization and spray drying procedures utilize the pre-concentrate product for pulverization in the dryer camera, which has a dry matter content ranging from 46–48% and is produced by evaporation under vacuum at a relatively low temperature (~65 °C). This is utilized in optimizing and aiding the operation [2].

5.6. Other GM Products

The whey protein in goat milk contains more α -lactalbumin than the whey in CM. However, it is typically discarded or fed to animals as a nutritional supplement and little information is available [136]. In addition, numerous products are now manufactured from whey GM, including whey GM beverages (flavored), chewable tablets, sports supplements, and whey protein concentrate. Customers in some countries may discover breakfast cereals with GM, salty and sweet pies, and infant food produced from goat cheese and milk. The quantity and variety of these products are expanding. Whole goat milk that has been industrialized is also utilized for pet consumption. This covers pet care items (cosmetics) manufactured in some areas [2].

A variety of chocolates and candies produced from goat milk are available now in different regions. "Cajeta" is considered a Mexican candy produced from GM. It is a caramel sauce prepared from GM. It is available in various flavors, the most common of which are caramel or Quemada (simple), liquor, and vanilla flavor [110]. It is typically eaten as a dessert by itself or a topping for fruit or ice cream in Mexico and several South American nations. In addition, it is utilized for the manufacturing of Alfajores (caramel sandwich cookies) in countries such as Chile, Argentina, Peru, and Uruguay. Glorias and Queso de nuez (nuts) and Chongos Zamoranos (cinnamon flavor) are classic Mexican candies made from goat milk. Fudge, a famous American goat milk candy, is usually chocolate. Doce de Leite is a typical Brazilian confection made primarily of cow milk in the Minas Gerais state. However, a similar type of candy is also manufactured with GM. It is sweet and pasty and is usually available plain or with coconut and dehydrated fruits or Brazilian nuts. Rapadura, a sugarcane-based traditional Brazilian sweet, is also available. Some producers from Brazil create GM Rapadura (Rapadura de Leite de Cabra) by combining sugarcane with goat milk. It may contain coconut, peanuts, or chocolate [2].

6. Conclusions

According to the critical points discussed in this review, GM milk might be deemed a viable option for all age groups' consumption compared with other animal species' milk. Apart from providing various dietary benefits, GM also provides several health benefits for humans. Various goat milk-based products are available on the market, which act

as functional foods responsible for exhibiting potential nutritional and health benefits after consumption. Different technologies have been developed to enhance the sensorial, textural, and overall quality of GM and its products, resulting in reducing their possible contamination and spoilage and increasing consumer acceptance. However, more thorough research needs to be carried out to explore: (i) the potential health benefits of goat milk; (ii) leveraging the use of modern technology in the processing of GM and its products. More attention should also be given to the development of GM production, including the monitoring of different operating conditions on farms such as goat farm sustainability and paying special attention to the farmer's quality of life can help in enhancing the overall GM production system. Additionally, a new dimension in the production of functional foods based on GM could emerge due to its substantial bioactive potential.

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