Goat Milk

- Nutrition and health aspects

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Introduction

Goat farming has increased significantly during the last decades. From 1980 till 1999 the farm animal numbers have increased by 55% and the goat milk production by 58% [1]. However, these numbers are likely to be much greater, because of the large amounts of unreported home consumption, especially in developed countries [1]. In Europe, goat milk is primarily produced in the Mediterranean countries; Greece, Italy, Spain and France, and here goat cheese production is extensively increasing [2]. Although goats are present in all of the continents, figure 1, the goat sector has not been well supported publicly or academically when compared with other animal production sectors, especially the cow milk sector [2].

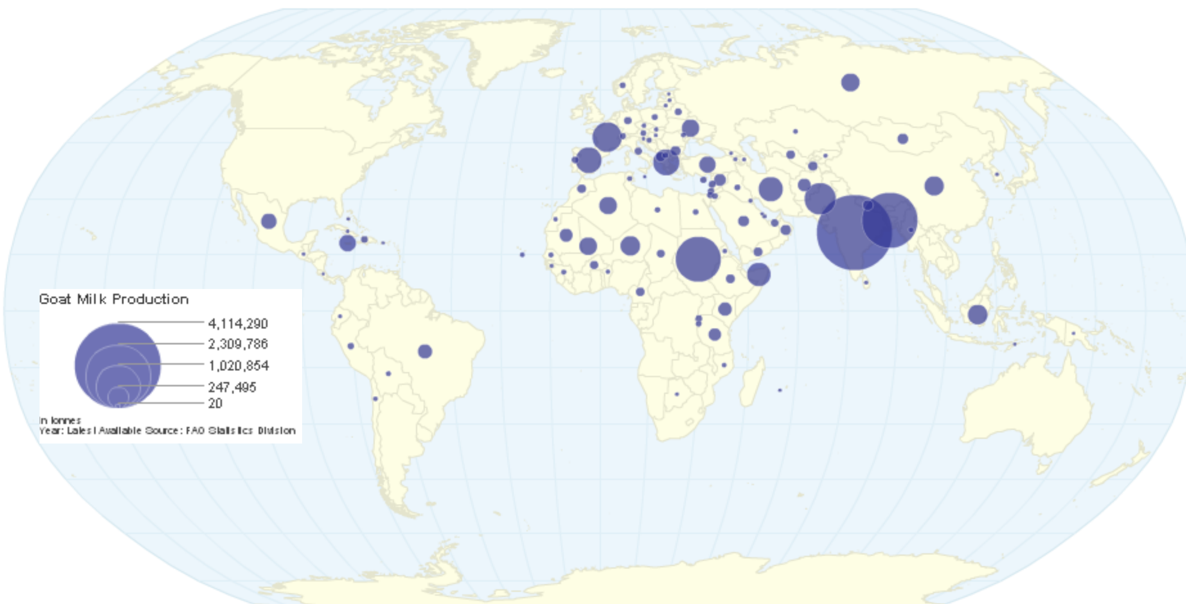

Figure 1. *Goat milk production in the world (FAO Statistics Division, 2011)*

Goat milk is usually compared with cow milk. Cow milk production is much cheaper and the volumes are much larger, and so cow milk has a lower market price [2]. The cow milk composition is expected to have minimal changes throughout the year, because of negligible seasonal variations due to year-round breeding. Commercial goat milk production is more expensive because of lower productivity, seasonal variations and the need of bigger animal herds. The goat milk and its products are therefore an essential niche in the total dairy industry sector [3].

Besides production differences, goat milk differs from cow milk in having better digestibility, alkalinity, buffering capacity and certain therapeutic values in medicine and human nutrition [3].

Many anecdotal experiences about nutritional and medical benefits of goat milk have been reported in the popular press and on the web. But few technical studies have been conducted and published in refereed journals or technical books. In this summary the nutritional content of goat milk is compiled and some selected medical conditions which have been scientifically investigated in relation to goat milk consumption are summarized. However, it is important to note that very few human studies are performed within the area. Most common are animal and *in vitro* studies, which may give a hint of how it would work and function in humans, though it needs to be investigated in humans before health benefits can be proved. As mentioned above there are innumerous reports found on the web presenting non-proven health benefits from goat milk in different medical conditions. Examples of such conditions are: autism, rheumatism, arthritis, asthma, eczema, migraines, stomach ulcers, liver complaints, chronic catarrh, cystic fibrosis, gallbladder diseases, childhood epilepsy and stress-related symptoms such as insomnia and constipation [4]. Since these conditions are not scientifically confirmed, they will not be analyzed and reviewed here.

Lipids

Lipids are the most important components of milk in terms of cost, nutrition and physical and sensory characteristics that impart to dairy products [3]. The biggest component, about 97%, of the lipid fraction of goat milk is triacylglycerols (TAG), including a large number of esterfied fatty acids [5]. The lipid fraction also contains simple lipids as diacylglycerols, monoacylglycerols and cholesterol esters, complex lipids as phospholipids and liposoluble compounds as sterols, cholesterol esters and hydrocarbons [3].

Fat globules

The lipids in milk are present in the form of globules. In goat milk the lipid globules are significantly smaller than in cow milk ("natural homogenized"). They have both a smaller diameter and the size distribution of globules has a larger proportion of smaller particles than in cow milk. Total fat content and fat globules size and distribution affects the viscosity of milk and are of importance for the processing and manufacturing of milk products [6]. The large number of fat globules with small diameter makes the in goat milk more digestible. This is because the total surface area of the globules is very large, which enhance enzymes in the gastrointestinal tract with pancreatic lipase activity to effectively get in contact with the lipids [7].

According to some authors natural homogenization of goat milk is, from a human health standpoint, much better than the mechanically homogenized cow milk product. Oster presented a hypothesis in 1977 which includes a theory about the enzyme xanthine oxidase. It appears that when fat globules are forcibly broken up by mechanical means, it allows an enzyme associated with milk fat, known as xanthine oxidase, to become free and penetrate the intestinal wall [8]. Once xanthine oxidase gets through the intestinal wall and into the bloodstream, it is capable of creating scar damage to the heart and arteries, which in turn may stimulate the body to release cholesterol into the blood in an attempt to lay a protective fatty material on the scarred areas. This can lead to arteriosclerosis, and thereby cardiovascular disease. It should be noted that this effect is not a problem with natural (unhomogenized) cow milk. In unhomogenized milk this enzyme is normally excreted from the body without much absorption [9].

Oster´s hypothesis described above has been criticized and challenged. According to Clifford *et al* [10], the theory has not been substantiated and no experimental evidence support the hypothesis. In a review by Michalski *et al* [11], the cow xanthine oxidase as risk factors of arteriosclerosis is also discussed, and the conclusion is that there are no sufficient proofs regarding harmful enzyme effects.

Fatty acids

Another significant difference between goat and cow milk lipids is in the composition of their fatty acids. Goat milk contain much higher proportion of short- and medium-chain fatty acids, especially butyric, caproic, caprylic, capric, lauric, myristic, palmitic, linoleic acid and α-linolenic acid [12], with the chain lengths of 4-18 carbon atoms, table 1. Three of these (caproic, caprylic and capric acids) have actually been named after goats, because of their predominance in goat milk [1]. According to Ceballos *et al*. [12] goat milk also have higher proportions of n-3 and n-6 polyunsaturated fatty acids (PUFA), as well as conjugated linoleic acid (CLA).

Short- and medium chain fatty acids, as well as medium chain triacylglycerols (MCT), have become established medical treatments for several clinical disorders. The MCT are absorbed intact in the intestine and do not undergo degradation and reesterfication processes. Micelle formation is not required for absorption, since the molecules are taken up directly into the portal vein [7]. This contributes to easier and faster digestion. The MCT fatty acids also have a unique ability to provide direct energy instead of being deposited in adipose tissues [13]. They also lower serum cholesterol and inhibit and limit cholesterol deposition. Altogether, these properties are known to be beneficial for several clinical conditions including cardiovascular conditions, malabsorption syndromes, chyluria (lymphatic fluid in the urine), steatorrhea (excess of fat in feces), hyperlipoproteinemia (elevated levels of lipoproteins in the blood), intestinal resection, premature infant feeding, infant malnutrition, epilepsy, cystic fibrosis, coronary by-pass and gallstones. The high content of n-3 and n-6 polyunsaturated fatty acids and conjugated linoleic acid (CLA) seems to account for cardioprotection and anticancer activities [14].

Table 1. [12] *Fatty acid composition (% of total fatty acids) of goat milk (n=30) from Granadina goats and cow milk (n=30) from Holstein Friesian cows*.

Fatty acid		**Goat milk**	**Cow milk**	
4:0	butyric acid	1.27	3.84	*
6:0	caproic acid	3.28	2.28	*
8:0	caprylic acid	3.68	1.69	*
10:0	capric acid	11.07	3.36	*
12:0	lauric acid	4.45	3.83	*
14:0	myristic acid	9.92	11.24	*
16:0	palmitic acid	25.64	32.24	*
18:0	stearic acid	9.92	11.06	NS
18:1 n-9	oleic acid	23.8	21.72	NS
18:2 n-6	linoleic acid	2.72	2.41	*
	CLA tot	0.68	0.45	*
18:3 n-3	α-linolenic acid	0.53	0.25	*
	PUFA n-6	2.81	2.53	*
	PUFA n-3	0.51	0.25	*
	PUFA tot	4.08	10.49	*

*= significant difference between goat and cow milk
NS= no significant difference

Agglutination

Agglutination means clustering of fat globules and that is what gives the creaming effect of milk. The main factor responsible for formation of a cream layer is shown to be a heat denaturable protein absorbed on cold fat globules. The protein is called agglutinin and promotes the clustering of fat globules [15]. Agglutinin is however absent in goat milk, which gives it a slower creaming rate and contribute to facilitate digestion and absorption [6].

Carbohydrates

Lactose

Lactose is the major carbohydrate in goat milk, and the content is slightly lower than in cow milk [2]. It is synthesized from glucose and galactose in the mammary gland, where the milk protein α-lactalbumin plays an important role [3]. Lactose is a valuable nutrient, because it favors intestinal absorption of calcium, magnesium and phosphorous, and the utilization of vitamin D [16]. It also is of major importance during milk synthesis, and during secretion of milk into the duct system of the udder [3].

Oligosaccharides

Other carbohydrates found in goat milk are oligosaccharides, glycopeptides, glycoproteins and nucleotides in small amounts. Goat milk is significantly rich in lactose-derived oligosaccharides compared to cow milk [2]. Milk oligosaccharides are thought to be beneficial to human nutrition because of their prebiotic and anti-infective properties [17]. In animal models, goat milk oligosaccharides have been shown to have anti-inflammatory effects in induced colitis [18, 19]. These results could be useful in the management of inflammatory bowel disease [19].

Nucleotides in milk are also of interest since they are the glycosyl donors for glycosyltransferase in milk and mammary gland, and are the precursors of glycoproteins, glycolipids and oligosaccharides in the biosynthesis of milk. Goats have remarkably high nucleotide content in their milk [3].

Proteins

There are two distinct phases of milk proteins; an unstable micellar phase composed of casein and a soluble composed of whey proteins. The caseins constitute about 80% of the proteins and are classified as α_{s1}-, α_{s2}-, β and κ-caseins, while the major whey proteins are β-lactoglubulin and α-lactalbumin [2], table 2.

α_{s1}-casein and β-lactoglobulin are important allergens in cow´s milk allergy, and the differences in protein content and composition between cow and goat milk have emphasized goat milk as an alternative to people suffering from cow´s milk allergy. Goat milk contains a smaller amount of α_{s1}-casein than cow milk, although appreciable quantitative variability exists, and the antigenicity of β-lactoglobulin can be partially eliminated by certain treatments [20]. However, many studies show that people that are allergic to cow milk proteins often cross-react to proteins in goat milk [21-24]. Goat milk as a substitute for people with cow milk allergy is further discussed under "Nutritional and therapeutic values of goat milk".

Table 2. [25] *Protein faction composition (% of total protein) of goat milk from Granadina goats and cow milk from Holstein Friesian cows*.

	Goat milk	Cow milk
Total casein	81.7	82
α_{s1}-casein	16.9*	32.6
α_{s2}-casein	11.5	8.5
β-casein	47.4	30.2
κ-casein	5.9	10.7
α-lactalbumin	5.5	6.4
β-lactoglobulin	10.5	10.1

*The levels of α_{s1}-casein vary significantly between milk from different goat species.

Caseins

Goat milk contains lower amounts of the α_s-casein, higher amounts of the β-casein fractions and approximately equal amounts of the κ-casein fractions compared to cow milk. The major protein in cow milk is α_{s1}–casein, while in goat milk it is β-casein. Goat milk also contains some α_{s1}-casein, but the amount and genetic variants differ between goat populations [3]. The different genetic variants of α_{s1}–casein have been extensively studied since it is assumed to be an important allergen in cow milk allergy [12]. Eighteen genetic types have been identified in goat milk; A, A´, B1, B2, B3, B4, B´, C, E, F, G, H, I, L, M, N, 01 and 02. All the variants have been connected to the amount of α_{s1}-casein present in goat milk. Three types (N, 01 and 02) are associated with absence of α_{s1}-casein, F and G indicate low levels, E and I medium levels and A, A´, B1, B2, B3, B4, B´, C, H, L and M are associated with high levels of α_{s1}-casein in goat milk [26].

The different genetic types give rise to difference in digestibility. The more α_{s1}-casein in milk the longer digestion, which depends on that α_{s1}-casein is only partly digested by gastric juice enzymes. It is not totally hydrolyzed until it reaches duodenal enzymes [27]. The digestibility is also affected by prior heating of the milk. When heating, the proteins denaturate and aggregate, which make them more resistant against hydrolysis and thereby get a longer digestion time. The amounts of α_{s1}-casein also affect coagulation, flavors and cheese making properties [2].

The casein micelles in goat milk differ from those in cow milk in having greater β-casein solubilization, more calcium and phosphorus and lower heat stability [28]. The curd is also weaker which directly influence the digestibility in the gastrointestinal tract. The acidic environment in the gastrointestinal tract causes the formation of smaller and less dense clusters in goat milk compared to cow milk [2].

Whey proteins

There are not many studies performed on different genetic variants of goat whey protein. But two types of β-lactoglobulin have been identified in goat milk and three variants of α-lactalbumin [29]. However, their physiological importance is unknown, except for α-lactalbumin that is required for lactose synthesis. Both the percentages of β-lactoglobulin and α-lactalbumin are lower in goat milk compared to cow milk [3].

Bioactive peptides derived from goat milk proteins

Enzymatic hydrolysis of milk proteins can release fragments called bioactive peptides. These are able to exert specific biological activities such as antihypertensive (counteract high blood pressure), antimicrobial and immunomodulant. The peptides are formed during gastrointestinal digestion and/or during food processing and are regarded as highly prominent components for health promoting foods.

Angiotensin converting enzyme inhibitory peptides

Angiotensin* converting enzymes (ACE) are located in different tissues and regulate several systems that affect blood pressure. ACE inhibitory peptides are mainly derived from milk proteins and are especially interesting because of their beneficial effects in the treatment of hypertension (high blood pressure). The peptides are for example released from the milk proteins by hydrolysis with digestive enzymes or by fermentation with proteolytic starter culture. ACE inhibitory peptides may be extracted both from goat whey and casein proteins [3].

**angiotensin= peptide hormone involved in controlling blood pressure*

Antimicrobial peptides

Milk proteins have also been proved to be precursors for antimicrobial peptides. The most well known peptides are those derived from lactoferrin. Lactoferrin is an iron-binding glycoprotein which main function is iron transport. It is involved in many physiological functions, including regulation of iron absorption and immune responses. It also exhibit antioxidant activity and has both anticarcinogenic and anti-inflammatory properties. However, its antimicrobial properties are its most widely studied function [30]. Antimicrobial activity has also been detected in α_{s2}-casein that has went through degradation by the gastrointestinal enzyme pepsin [3].

Antithrombotic peptides

K-caseino-macropeptide (κ-CMP) is a main component of whey and is obtained as a by-product in cheese-making. Goat κ-CMP and its decomposition products from trypsin (enzyme in the gastrointestinal tract) treatment have been found to inhibit human platelet aggregation. That is a crucial incidence in cardiovascular diseases called thrombosis [31].

NPN compounds, free amino acids and some minor peptides

NPN compounds

Many different bioactive compounds have been isolated from goat milk. Among them, there are definitely some that have certain biological impacts on humans [3]. Non-protein nitrogen (NPN) compounds in goat milk are examples of these, but more investigations are needed to clearly define their biological functions. According to some authors, the high NPN content in goat milk compared to cow milk is one of the reasons why it is identified as a "healthy" milk [2].

Free amino acids

The amounts of free amino acids are different between goat and cow milk. Six of 10 essential amino acids are reported to be higher in goat milk; threonine, lysine, isoleucine, cystine, tyrosine and valine [1]. Their metabolic effects have not been studied much in goat milk, however the higher content of cysteine (derived from cystine) has been shown to improve intestinal absorption of copper and iron in a rat model of malabsorption syndrome [32].

Taurine is the most representative free amino acid in goat milk [33, 34], and the concentration is much higher than in cow milk [35]. Taurine is involved in many different roles in the human body, such as growth and brain development, formation of bile salts, modulation of calcium flux and the stabilization of membranes as an osmoregulator and/or by attenuating toxic substances. Taurine deficiency in human tissues may lead to cardiomyopathy, epilepsy, lack of growth among others [36].

Minor peptides

The concentrations of folate-bindning protein in goat milk are higher than those of cow milk. The protein has high affinity to bind folate, and thereby makes it unavailable for humans to digest and absorb. In addition, the actual folate content is lower in goat milk. Other important peptides in goat milk are iron-binding lactoferrin (mentioned above) and transferrin [3]. Transferrin is, as lactoferrin, an iron-binding blood plasma glycoprotein, but with the main function to control levels of free iron in biological fluids.

Minerals

Goat milk is reported to have higher content of potassium [3, 28, 37], chloride [3, 4, 28], calcium [3, 4, 28], phosphorus [3, 4], selenium [3, 38, 39], zinc [38, 39] and copper [39] than cow milk. However, it is important to know that the goat feed may have big effects on the mineral content of the milk.

Potassium is important for the acid/base balance and also for the function of muscles, nerves and kidneys. Chloride maintains fluid balance, blood pH and osmotic pressure. It also affects the liver function and is a substantial component in hydrochloric acid (HCl) in the gastric juice of the stomach. Calcium is of importance for building up the bone structure, but also affects function of muscles, nerves and blood coagulation. Similar to calcium, phosphorous is involved in building bone structure, muscle and nerve functions, but it also participate in energy production. Selenium is involved in the cell protection against free radicals. It affects some immune cells (leukocytes) in a positive way and it protects the body against heavy metals. Zinc is a key component in several enzymes that are involved in transport of carbon dioxide, protein production and it also cooperate with the hormone insulin which regulates metabolism of carbohydrates. Copper is also needed by many enzymes. It affects the metabolism of iron and oxygen, and also the cell defense against free radicals.

The iodine content of milk is also highly dependent on what the cattle are fed, and thereby the concentrations usually vary seasonally. Iodine is a vital component in two thyroid enzymes that regulate metabolism and stimulate growth and development of the body. Iodine deficiency is the major cause of goiter.

Studies in healthy rats have shown that the uptake of calcium [40], iron [40], copper [39], zinc [39] and selenium [39] is higher from goat milk than cow milk. The same results, including iron [32], copper [32], zinc [38] and selenium [38], have been shown in rats that went through resection to provoke malabsorption syndrome.

Table 3. *Vital minerals necessary for the human body and metabolism.*

Mineral		Needed for:
Ca	calcium	bone structure, muscle and nerve functions and blood coagulation
Cl	chloride	pH balance, maintain blood volume and pressure, constituent of hydrochloric acid in gastric juice, affect liver function
Cu	copper	enzymes involved in iron and oxygen metabolism and cell defense against free radicals
Fe	iron	oxygen transport from lungs to blood, major component in hemoglobin and myoglobin
P	phosphorous	bone structure, muscle and nerve functions and energy production
I	iodine	thyroidal hormones involved in protein metabolism
K	potassium	pH balance and function of nerves, muscles and kidneys
Mg	magnesium	bone structure, muscle and nerve functions and activation of enzymes vitally for cell functions
Se	selenium	cell protection against free radicals, affect white blood cells in the immune system and protect against heavy metals
Zn	zinc	enzymes involved in CO2 transport, gene formation, protein production and co-operate with insulin which regulate metabolism of carbohydrates

Vitamins

Milk contains most known vitamins. Goat milk has a higher vitamin A content than cow milk because goats convert all β-carotene from foods into vitamin A in the milk [2, 3]. For the same reason, goat milk is always whiter than cow milk. Goat milk also contain sufficient amounts of thiamin (vitamin B1), riboflavin (vitamin B2), niacin (vitamin B3), pantothenic acid (vitamin B5) and vitamin C in relation to human needs [2-4, 37]. Both goat and cow milk have low concentrations of vitamin B6 and vitamin D, which are both important during infancy [2, 3]. Goat milk is also deficient in folic acid and vitamin B12 [2, 3, 37]. Folate is necessary for cell metabolism, the synthesis of red blood cells and it prevents neural tube defects in fetus. Both folate and vitamin B12 deficiency can cause megaloblastic anemia in infants.

Table 4. *Vital vitamins necessary for the human body and metabolism*.

Vitamin		**Needed for:**
A	rethinol	vision, skin, mucous membranes, fetal development, growth
B1	thiamine	carbohydrate metabolism, muscle and nerve functions, energy production
B2	riboflavin	energy production, fat, carbohydrate and protein metabolism
B3	niacin	energy production, fat and carbohydrate metabolism
B5	pantothenic acid	carbohydrate, amino acids and fat metabolism
B6	pyrodoxine	protein and carbohydrate metabolism
B12	kobalamine	production of red blood cells, functions of nervous system
C	ascorbic acid	formation of collagen in connective tissues, iron absorption, cell protection against free radicals, antioxidant
D	calciferol	calcium and phosphate metabolism
E	α-tocopherol	cell protection against free radicals
Folic acid	folate	protein production, cell metabolism, production of red blood cells, prevents neural tube defects in fetus

Nutritional and therapeutic values of goat milk

Digestibility

The most appearing property of goat milk is its rather superior digestibility. The digestibility of goat milk can be attributed to its casein curd which is both softer and smaller than that produced by cow milk. This makes it more easily accepted by the human digestive system [3].

The size of the fat globules also affects the digestibility since it provides a better dispersion and a more homogenous mixture of fat. The large total surface area of the globules makes it easier for enzymes to reach and get in contact with the lipids [6].

The high proportion of short- and medium-chain fatty acids in goat milk contributes to easier and faster digestion. Lipases attack ester linkages of such fatty acids more readily than those of longer chains. Medium chain triacylglycerols in goat milk are absorbed intact in the intestine and do not undergo degradation and reesterfication processes. Micelle formation is not required for absorption, since the molecules are taken up directly into the portal vein [7].

The levels of α_{s1}-casein also affect digestibility. The more α_{s1}-casein in milk the longer digestion, which depends on that α_{s1}-casein is not totally hydrolyzed until it reaches duodenal enzymes [27]

Finally, goat milk does not contain the protein agglutinin that promotes clustering of fat globules. The absence of clustering facilitates digestion and absorption [15].

Malabsorption disorders

Malabsorption disorders are states arising from abnormality in absorption of food nutrients across the gastrointestinal tract. It can be caused as side effects or symptoms of several different diseases as: HIV, Crohn´s disease, cow milk allergy, lactose intolerance, cystic fibrosis and different forms of cancer. Malabsorption cause deficiency of various nutrients, especially anaemias of vitamin B12, folic acid and iron but also other minerals, vitamins and macro nutrients.

Malabsorption syndrome is often studied in rat models where the condition is provoked by resection of about 50% of their small intestine. When comparing diets of goat and cow milk respectively, studies show improved digestive utilization of fat and protein, and higher apparent digestibility coefficient and absorption of calcium, phosphorus, magnesium, iron, copper, zinc and selenium [7, 32, 38]. Suggested explanations of these results are the good digestibility of goat milk because of its structure of fat globules and composition of fatty acids, and its high content of many minerals and vitamins. The good metabolic utilization of several minerals in goat milk is suggested to be due to higher protein content, cysteine levels and amount of vitamin C and D compared to cow milk [38].

Inflammatory bowel disease (IBD)

IBD comprises two different but closely related conditions, ulcerative colitis and Crohn´s disease. The hallmark of IBD is chronic and relapsing inflammation of the intestine, but there are important differences from Crohn´s disease with regard to pathophysiology and treatment. Thus, ulcerative colitis affects the large intestine at the mucosal level, whereas Crohn´s disease is characterized by transmural inflammation and may involve any segment of the gastrointestinal tract, although the majority of cases show ileocolonic involvement [19]. IBD is an important health problem because of its effect on the patient´s quality of life and because of its high prevalence, which has increased in the past few years. Despite intense investigative efforts, the cause of IBD is essentially unknown [46].

IBD can often be treated pharmacologically, and sometimes also with prebiotics and/or probiotics. But additional treatments are much warranted. Two studies in Spain have evaluated the effect of oligosaccharides isolated from goat milk in rat models of induced colitis [18, 19]. Colitis could be compared with the intestinal inflammation that occurs in IBD. The oligosaccharides from goat milk are shown to have an anti-inflammatory effect. The expected decrease in body weight, increased colon size and extension of necrotic lesions are prevented by the oligosaccharides. They also decreased clinical symptoms (diarrhea and bloody stools) and caused a weaker immune response with less neutrophil infiltration [18]. The control group got regular rat chow without the efficient oligosaccharides.

Cardiovascular diseases

Cardiovascular disease (CVD) is the most common cause of death in industrialized countries. It includes many diseases that involve heart and blood vessels; coronary heart disease, high blood pressure, arrhythmias and atherosclerosis. The main cause of CVD is atherosclerotic plaque development in blood vessels that eventually leads to cardiovascular incident. The risk factors influencing atherosclerosis are lifestyle (smoking, diet and exercise), high blood pressure, dyslipidemia, diabetes and obesity [47].

The progress of atherosclerosis is slow and may start in childhood. The initiation of the process is unknown, but a major mechanism seems to be retention of atherogenic lipoproteins in the arterial walls. Low-density lipoprotein (LDL) is such atherogenic lipoprotein which transports cholesterol from the liver to the blood vessels and is often called “the bad cholesterol”. The “good” cholesterol is the high-density lipoprotein (HDL) which transports cholesterol from the vessels to the liver where it is degraded [47].

The oxidative modification of LDL (ox-LDL) plays a pivotal role in atherosclerosis progression. This implies that antioxidants, which could inhibit LDL oxidation, should be effective in suppressing atherosclerosis [47].

Goat milk is rich in medium-chain triglycerides (MCT) including fatty acid esters of caproic, caprylic and capric fatty acids. These MCT have been shown to have a lowering effect on plasma cholesterol in rat models [48, 49], and also to inhibit and/or limit cholesterol deposition in the tissues [13]. Altogether MCT found in goat milk act anti-atherogenic.

An *in vitro* study have shown that cells isolated from humans who had been drinking goat milk from different breeds were triggered by components in the milk to release nitric oxide (NO). In turn, the NO reaches the blood stream via lymphatic route, thus provoking vasodilation and exerts a cardioprotective and anti-atherogenic affect [50]. It is also suggested that NO protects the blood vessels from atherogenic plaque accumulation [51].

In 2003 Kullisaar *et al* [42] performed a human intervention study to investigate the effects of fermented goat milk versus regular goat milk on oxidative stress. Humans who ate fermented goat milk had an anti-atherogenic effect from decreased LDL oxidation. In addition, both fermented and regular goat milk had an antioxidative effect when measuring total antioxidative activity and status respectively. The group who ate fermented goat milk also had lower levels of urine isoprostanes which is a further parameter showing on less oxidative stress. Thus the study shows both anti-atherogenic and antioxidative effects from fermented goat milk.

Cow milk allergy

Cow milk allergy is a common disease in infancy and childhood, and its prevalence is about 2.5% during the first three years of life [57]. Cow milk is an important nutritive source and is often one of the first types of food proteins that infants get introduced to. After or parallel to breast feeding, the children are usually given cow milk based formula. But for children who immediately develop symptoms after ingestion, a substitute is needed. The most common alternatives to cow milk are soy milk and hydrolysed formulas. However, hydrolysed formulas have an unpleasant taste and are quite expensive, whereas soy formulas have the potential to evoke allergic reactions. For that reason, other mammalian milks could be of interest to replace cow milk, including goat milk.

Cow milk allergy is an IgE-mediated allergy which means that the body starts to produce IgE antibodies against certain proteins (allergens) in cow milk for unknown reasons. When the person ingests milk repeatedly, an immune reaction including the IgE antibodies will occur and the person gets allergic symptoms as eczema, respiratory symptoms as hay fever, wheezing or asthma, gastrointestinal symptoms, or even anaphylaxis.

The proteins α_{s1}-casein and β-lactoglobulin are important allergens in cow´s milk allergy. The allergy-causing properties of β-lactoglobulin can be partially eliminated by certain treatments as extended heating. But caseins maintain the capability of binding to IgEs even after a strong denaturating process [20]. Since the content of α_{s1}-casein is very high in cow milk but relatively low in goat milk, the latter has been suggested as an alternative milk source for cow milk allergics. Goat milk contains smaller amounts of α_{s1}-casein than cow milk although, as mentioned above, appreciable quantitative variability exists. Some breeds have no α_{s1}-casein but some have relatively high levels.

Some people with cow milk allergy do tolerate goat milk, probably because of low α_{s1}-casein levels. However, several studies report extensive cross-reactivity between cow and goat milk, caused by cow milk-specific IgE antibodies [22, 24]. Because of the cross-reactivity all scientific reports dissuade persons with cow milk allergy to ingest goat milk.

Both *in vitro* and animal studies have shown that cow milk is more allergenic then goat milk. The in vitro study show that cow milk proteins have higher binding capacity to IgE and IgG than goat milk protein [21]. In animal models cow milk is shown to cause higher lymphocyte proliferation, IL-4 production, histamine secretion [58] and IgG production [25, 58], which are all parameters indicating more extended allergic inflammation.

Lactose intolerance

Goat milk, as well as cow and human milk, contains lactose. Despite that, many people with lactose intolerance do tolerate to drink goat milk. It has been hypothesized that the reason is the superior digestibility of goat milk. Goat milk is more completely and easily absorbed than cow milk, leaving less undigested residue behind in the colon to ferment and cause the uncomfortable symptoms of lactose intolerance [1, 7]. It may also be that the patients are not lactose intolerance, but instead are allergic to the major α_{s1}-casein protein in cow milk, which usually is lower or absent in goat milk. The symptoms are almost identical in lactose intolerance and milk protein allergy.

Activate immunity

Even if goat milk might not be a perfect alternative for people with cow milk allergy, very recent studies have showed immunomodulatory effects from goat milk both in *in vitro* and human studies. Jirillo *et al* [50] recently investigated the effects of goat milk on human blood cells in terms of nitric oxide (NO) and cytokine release. The results demonstrated that goat milk was able to activate NO release from blood cells as well as triggering of cytokine production (IL-10, TNF-α and IL-6).The NO release could have cardioprotective effects in the milk consumer, and also expose antibacterial activity and thereby prevent infections. TNF-α is a pro-inflammatory cytokine, IL-6 is an acute phase reactant and growth factor for B cells and IL-10 is an anti-inflammatory cytokine. This mix of released cytokines has been suggested to maintain the immune homeostasis by goat milk [50].

In 2010 Amati *et al* [59] published data from a human intervention study where immune response in old people (72-97 years) was investigated after goat milk intake. Senescence is characterized by progressive decline in immune functions. It accounts for the increased susceptibility of old people to infections, tumors and autoimmune diseases. Nutrition has been found to be fundamental in the mechanism of immune recovery in elderly. The results from the intervention study showed that goat milk seemed to reduce the exaggerated acute phase response in elderly because of declining levels of IL-6. These results are somewhat contrarious to the *in vitro* study mentioned above. Thus, more research is needed to understand the immunomodulatory effects from goat milk.

Infancy intake

Feeding goat milk to infants has been, and still is, popular in many parts of the world. The scientific thoughts about goat milk in infant nutrition are contradictory. But all agree on that unpasteurized goat milk should not be given to infants and children, since this is directly vitally. Unpasteurized milk could contain bacteria or viruses leading to life threatening infections as Q fever, toxoplasmosis, tuberculosis or brucellosis [60-63].

Pasteurized goat milk or formula based on goat milk could however be an option to cow milk. Though primarily commercially produced formulas are recommended, since these usually are fortified with folic acid, vitamin B12 and iron, that are too low in regular goat milk [61, 63]. Case reports have been published on infants who were fed homemade goat milk formulas and then were diagnosed with megaloblastic anaemia caused by folate and/or vitamin B12 deficiency [64].

Another report presents a case where an infant was exclusively fed goat milk, which led to azotemia (abnormally high levels of nitrogen compounds in the blood), hypernatremia (electrolyte imbalance caused by elevated sodium levels) and hemorrhages in the brain. This was caused by the high levels of sodium in goat milk compared to human milk. The kidneys of infants´ are immature and cannot handle high sodium concentrations [65].

Despite the insufficient content of certain vitamins and minerals, goat milk or goat milk formulas with adjusted nutrient content could be an alternative to cow milk. Two studies have investigated effects of goat milk and cow milk on weight gain and fat absorption in healthy and undernourished infants and children respectively [66, 67]. When giving malnourished children (1-5 years) goat or cow milk, weight gain and fat absorption were similar in both groups. The milks used in the study were modified to be as identical as possible concerning nutrient, by adding vitamins and minerals [66]. The other study compared growth of healthy infants fed goat milk formula or cow milk formula (with comparable nutrient content). There were no difference in growth between the two groups [67].

Infantile colic

In countries with a tradition of goat milk consumption, parents and physicians often recommend goat milk or goat milk based formula to infants that suffer from colic. However, this is not been proved and accepted in clinical research. Colic is an easily identified childhood state with no clear treatment guidelines. The main theory is based on infantile colic as a gastrointestinal pathologic condition, and thereby several groups have examined diet modifications to treat colic. The foremost accepted theory resides in the contribution of whey hydrolysate to infantile colic by causing excessive gas production from poor gut digestion [68]. Maybe could the superior digestibility of goat milk be a possible property that might decrease colic symptoms?

Cancer

Goat milk has a high content of conjugated linoleic acid (CLA) [50]. Anti-carcinogenic properties of CLA have been reported against mammary [52] and colon cancer [53] in animal models, as well as *in vitro* models of human melanoma [54], colorectal [55] and breast cancer [56]. The mechanism by which CLA inhibit tumor development is not fully understood, although perturbation of the eicosanoid-dependent cell signaling systems, antioxidative effects, and disturbance of the receptor mediated actions of oestrogen have all been suggested [14].

Fermented goat milk

Fermented goat milk products are traditionally produced in the Mediterranean peninsula, Middle East, southern Russia and in the Indian subcontinent [2]. Lactic acid bacteria are often used as probiotic starter culture and health effects from these have been reported repeatedly. The viable lactic acid bacteria in fermented milk products have been associated with increased lactose intolerance, a well-balanced intestinal microflora, antimicrobial activity, stimulation of the immune system and anti-tumoural, anti-cholesterolaemic and anti-oxidative properties in human subjects [2].

The increasing interest in healthy diets is stimulating innovative development of novel scientific products in the food industry. In particular, many studies have been conducted on fermented milk [41]. Because of several reported health benefits from goat milk, this could be a future trend in the field of probiotic fermented milk products. Kullisaar *et al* [42] performed a human study in 2003 where they showed antioxidative and anti-atherogenic effects from fermented goat milk (*Lactobacillus fermentus* ME-3) in healthy subjects. Both reduce the risk for cardiovascular disease. In 2009 Minervini *et al* [43] developed fermented goat milk with a mixed starter culture (*Streptococcus thermophilus* CR12, *Lactobacilllus casei* LC01, *Lactobacillus helveticus* PR4 and *Lactobacilllus plantarum* 1288). It resulted in production of GABA, an inhibiting signal substance in the central nervous system, and provoked an *in vitro* ACE-inhibitory activity, which counteract high blood pressure. Recently, fermented goat milk (*Lactobacillus rhamnosus* CRL1505) was demonstrated to stimulate the mucosal immune system and improve the defense against intestinal and respiratory infections in a mouse immunosuppression model [44].

As mentioned above, one of disadvantage with goat milk is the almost nonexistent content of folic acid. In a fermented product this problem could be solved by using folate-producing bacteria during fermentation. Sanna *et al* [45] used a mix of *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus when fermenting goat milk*. It resulted in yoghurt with a significant quantity of folate and good sensory features.

Conclusions

Milk has long been and will always be consumed as part of a healthy balanced diet as it contains an impressive array of nutrients. Scientific data are continuously being published, documenting both already available knowledge concerning nutrient content but also new information about health and prevention of disease. However, research over the last decades has focused on cow milk, hence remaining goat milk an appealing area of investigation [69].

Goat milk products other than cheese and pasteurized milk are considered to be the dairy products with greatest marketing potential. Therefore, several characteristics of goat milk are currently the focus of increased research interest. Fermented goat milk incorporating live probiotic cells represent a group of products with great prospects in the future with regard to their nutritive and therapeutic properties [2].

The unique characteristics of goat milk have been fairly good surveyed regarding nutritional value and some health effects. However, the absence of human studies is extensive. Most studies are performed in animal models which may give indications of effects. But more human studies are required to be able to claim any health effects from goat milk products.

The superior digestibility of goat milk, the proper composition of fatty acids and its content of bioactive compounds seem to give properties suitable for treating or preventing certain medical conditions. Studies in animal models indicate that goat milk might have beneficial effects on malabsorption disorders and inflammatory bowel diseases. Fermented goat milk may reduce the risk of cardiovascular disease by antioxidative anti-atherogenic effects. Concerning goat milk ingestion among cow milk allergics, it is not recommended because of extensive cross-reactivity. Further investigations are necessary, both concerning above mentioned conditions and other diseases before one could enounce any health effects for certain.

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