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Goat milk in human nutrition

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Abstract

Goat milk and its products of yoghurt, cheese and powder have three-fold significance in human nutrition: (1) feeding more starving and malnourished people in the developing world than from cow milk; (2) treating people afflicted with cow milk allergies and gastro-intestinal disorders, which is a significant segment in many populations of developed countries; and (3) filling the gastronomic needs of connoisseur consumers, which is a growing market share in many developed countries. Concerning (1), very much improvement in milk yield and lactation length of dairy goats, especially in developing countries must be accomplished through better education/extension, feeding and genetics. Concerning (2), little unbiased medical research to provide evidence and promotional facts has been conducted, but is very much needed to reduce discrimination against goats and substantiate the many anecdotal experiences about the medical benefits from goat milk consumption, which abound in trade publications and the popular press. Goats have many unique differences in anatomy, physiology and product biochemistry from sheep and cattle, which supports the contention of many unique qualities of dairy goat products for human nutrition. Concerning (3), a few countries like France have pioneered a very well-organized industry of goat milk production, processing, marketing, promotion and research, which has created a strong consumer clientele like in no other country, but deserves very much to be copied for the general benefit to human nutrition and goat milk producers. The physiological and biochemical facts of the unique qualities of goat milk are just barely known and little exploited, especially not the high levels in goat milk of short and medium chain fatty acids, which have recognized medical values for many disorders and diseases of people. The new concept of tailor making foods to better fit human needs has not been applied to goat milk and its products so far, otherwise the enrichment of short and medium chain fatty acids in goat butter, and their greater concentration compared to cow butter, could have become a valued consumer item. Also revisions to human dietary recommendations towards admitting the health benefits of some essential fats supports the idea of promoting goat butter. While goat yoghurt, goat cheeses and goat milk powder are widely appreciated around the world, goat butter is not produced anywhere commercially in significant volume.

Keywords: Goat milk; Nutritional value; Short and medium chain fatty acids; Cow milk allergy; Goat cheese; Goat milk powder; Goat butter

1. Introduction

The importance of goats as providers around the world of essential food in meat and dairy products has been discussed and documented in many recent proceedings of national and international conferences (Gruner and Chabert, 2000; Boyazoglu and Morand-Fehr, 2001; Haenlein and Fahmy, 1999; Haenlein, 1992, 2001; Morand-Fehr and Boyazoglu, 1999; Rubino et al., 1999). This importance is also reflected in the largest animal number increase for goats during the last 20 years (FAO, 2001) (Table 1) and the largest increase in goat milk production tonnage compared to other mammalian farm animals. Milk production of goats is likely to be much greater

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Table 1
World numbers of mammalian farm animals (millions) since 1980 and annual milk production (1000 MT) (FAO, 2001)

	1980	1999	Change (%)
Animal numbers			
Goats	458	710	+55
Buffaloes	122	159	+30
Pigs	796	913	+15
Cattle	1216	1338	+10
Sheep	1096	1069	−3
Milk production			
Goats	7720	12161	+58
Buffaloes	44296	60334	+36
Cattle	423034	480659	+14
Sheep	7887	8026	+2

than in these official statistics, because of the large amounts of unreported home consumption, especially in developing countries.

More than any other mammalian farm animal, the goat is a main supplier of dairy and meat products for rural people, which is one of the three aspects of demand for goat milk: home consumption. This demand is increasing because of the growing populations of people, and here the old saying of the "goat being the cow of the poor people" is quite fitting.

The second aspect of demand for goat milk is the connoisseur interest in goat milk products especially cheeses and yoghurt in many developed countries. This demand is growing because of the increasing levels of disposable incomes.

The third aspect of demand for goat milk derives from the affliction of people with cow milk allergies and other gastro-intestinal ailments. This demand also is growing because of a wider awareness of problems with traditional medical treatments to such afflictions, especially in developed countries. These two later aspects of demand for goat milk are quite different from the "goat being the cow of the poor people"; here, goat milk is wanted or even needed by people of all income levels.

Despite the much larger volume available of cow milk, its much cheaper production usually and therefore lower market price, the production and marketing of goat milk and its products is therefore an essential niche in the total dairy industry sector. Especially the third aspect of demand for goat milk, the medical need, deserves in depth discussion and documentation, as it is widely accepted in practice and in anecdotal publications, but sparsely treated with biomedical research. Yet such research is essential for the future of the dairy goat industry, in developing as well as in developed countries. The question is asked, why produce and why buy goat milk? And it can only be answered satisfactorily, when there is convincing evidence for a special value of goat milk in human nutrition and well being. This paper is trying to review such evidence.

2. Nutritional studies with goat milk

Many anecdotal experiences about the nutritional and medical benefits of goat milk have been reported in the popular press, but few technical studies have been conducted and published in refereed journals or technical books (Beck, 1989; Freund, 1997, 2000). In the book by Beck (1989) the beneficial experiences with goat milk of 54 people or families in Australia have been documented, some with rather dramatic results. No other similar summary seems to have been published in other countries, although the bibliography of Freund (2000) contains in different languages and some in technical journals 32 citations for "Nutritional Value of Goat Milk", 45 for "Favoring Goat Milk", 26 for "Substitution of Cow Milk by Goat Milk", and 23 for "Milk Allergenicity". On the other hand, The International Dairy Federation Nutrition Week 2000, held in Ireland, did not have a single paper or poster presented on the role of goat milk in human nutrition and health, like neither in previous similar World Dairy Congresses (Miller, 2002), although the three section topics covered in 2.5 days were most appropriately "Role of Dairy Nutrition at Different Life Stages", "Health Effects of Milk and Other Food Components", and "Dairy Products with Nutritional Benefits".

The nutritional and health benefits of goat milk are related to a number of medical problems of people, foremost being food allergies with cow milk proteins the dominant food cause (Walker, 1964). The prevalence of cow milk allergy varies with countries and age of people, but exact data are lacking partly because differential diagnostic methods are difficult to perform in the apparent absence of standardized antigens (Kaiser, 1990), and because cow milk contains 18 different proteins against which antibodies in animal experiments have been demonstrated (Hanson and Mansson, 1961). β-Lactoglobulin is not present in human milk and has therefore been assumed to be the most offending protein in cow milk, however comparative studies showed no difference between the allergenicity of β-lactoglobulin and caseins (Buergin-Wolff et al., 1980; Taylor, 1986). In actual clinical skin prick-tests on 21 adult and 13 infant patients with suspected cow milk allergies, α-lactalbumin caused the most positive skin reactions. Ten of the 13 infants showed positive reactions, while only 5 of the 21 adults reacted (Kaiser, 1990). Of these 5 adults, only one had a weak IgG-titer (ELISA) against α-lactalbumin. However, seven of the infants showed positive RAST tests against whole milk with different levels of IgG-titers against any or all five major milk proteins. The highest titer of 1:3200 was found against α-s-casein and β-casein in an infant 2.5 years old, which was treated against problems of resorption with a hyposensibilization therapy. Generally, IgG-titers were higher against caseins than against whey proteins.

Cow milk allergy is considered a common disease with a prevalence of 2.5% in children during the first 3 years of life (Businco and Bellanti, 1993), occurring in 12–30% of infants less than 3 months old (Lothe et al., 1982), with an overall frequency in Scandinavia of 7–8% (Host et al., 1988), even as high as 20% in some areas (Nestle, 1987), and reported in Italy in 3% of children under 2 years of age (Bevilacqua et al., 2000). Treatment with goat milk resolved between 30 and 40% of the problem cases, and in one particular study 49 of 55 treated children benefited from treatment with goat milk.

The wide variety of genetic polymorphisms (Grosclaude, 1995) of the different caseins and whey proteins adds to the complexity of the cow milk allergy situation and difficulty to determine which protein is mainly responsible for an allergic reaction. However, it has now been shown that this genetic protein diversity may actually help identify which protein is the allergen, if genetic polymorphisms of milk proteins are specifically used for clinical tests (Bevilacqua et al., 2000). Guinea pigs had allergic reactions to goat milk with α-s-1-casein, similar to cow milk, which only has this protein polymorph, and which may explain the commonly found cross-immune reaction between cow milk and some goat milk. However, guinea pigs fed goat milk without this polymorph but instead with α-s-2-casein showed only in 40% an allergic reaction, which lead to the conclusion that goat milk lacking α-s-1-casein is less allergenic than other goat milk.

For goat breeding programs, this new knowledge could be a challenge and rewarding, especially since selection for or against α-s-1-casein is now practiced in some countries, because of differences in cheese yield and renneting (Remeuf, 1993; Moioli et al., 1998). Goat milk with the genetic trait of low or no α-s-1-casein, but instead with α-s-2-casein, has less curd yield, longer rennet coagulation time, more heat lability, and weaker curd firmness, which also may explain the benefits in digestibility in the human digestive tract (Ambrosoli et al., 1988).

Goat milk as a substitute for cow milk was studied in 38 children during a 5 months period (Mack, 1952). The children on goat milk surpassed those on cow milk in weight gain, height, skeletal mineralization, and blood serum contents of Vitamin A, calcium, thiamin, riboflavin, niacin and hemoglobin. Similar findings were obtained in studies with rats (Park et al., 1986). In French clinical studies over 20 years with cow milk allergy patients the conclusion was that substitution with goat milk was followed by "undeniable" improvements (Sabbah et al., 1997). In other French extensive clinical studies with children allergic to cow milk, the treatment with goat milk produced positive results in 93% of the children and was recommended as a valuable aid in child nutrition because of less allergenicity and better digestibility than cow milk (Reinert and Fabre, 1997; Fabre, 1997; Grzesiak, 1997).

In Spanish studies with rats, which had 50% of their distal small intestine removed by resection, simulating the pathological condition of malabsorption syndrome, the feeding of goat milk instead of cow milk as part of the diet resulted in significantly higher digestibility and absorption of iron and copper, thus preventing anemia (Barrionuevo et al., 2002). Also in these studies, the utilization of fat and weight gain was improved with goat milk in the diet, compared to cow milk, and levels of cholesterol were reduced, while triglyceride, HDL, GOT and GPT values remained normal (Alferez et al., 2001). It was concluded that the consumption of goat milk reduces total cholesterol levels and the LDL fraction because of the higher presence of medium chain triglycerides (MCT) (36% in goat milk versus

Table 2
Leaders[a] in goat milk production (FAO, 1990, 1994, 2001)

	Goat milk 1000 MT per year	Milk per goat per year (kg)	Goat milk of all milk in country (%)	Calcium supply (mg per person per day) (from milk + meat)	Protein supply (g per person per day) (from milk + meat)
India	3128	26	4	195	10
Bangladesh	1328	40	55	43	5
Sudan	1151	31	16	438	22
Pakistan	818	17	4	337	18
France	480	400	2	966	78
Greece	460	78	26	683	59
Iran	398	15	24	350	16
Somalia	390	31	51	796	17
Spain	350	121	7	529	61
9 Northern Mediterranean countries[b]	1840	123	1–26	511–966	40–78
10 Southern Mediterranean countries[c]	618	24	1–14	116–612	13–51

[a] Countries with >300,000 MT per year goat milk production.
[b] Portugal, Spain, France, Italy, Yugoslavia, Romania, Macedonia, Bulgaria, Greece.
[c] Turkey, Syria, Lebanon, Israel, Jordan, Egypt, Libya, Tunisia, Algeria, Morocco.

21% in cow milk), which decreases the synthesis of endogenous cholesterol. In an Algerian study of 64 infants with malabsorption syndromes, the substitution of cow milk with goat milk caused significantly higher rates of intestinal fat absorption (Hachelaf et al., 1993). In a study in Madagascar, 30 hospitalized undernourished children between 1 and 5 years of age were fed either cow or goat milk in addition to their regular diet (Razafindrakoto et al., 1993). Malnutrition is apparently frequent among children in Madagascar and cow milk is not affordable or available in sufficient quantities, while goat milk was cheaper to produce and more readily available. The children on goat milk outgained the cow milk children in bodyweight by 9% daily (8.53 g/kg per day $\pm$ 1.37 versus 7.82 $\pm$ 1.93) over the 2-week trial period and fat absorption tended to be better in the goat milk children. Thus goat milk was again recommended as a "useful alternative to cow milk for rehabilitating undernourished children".

Goat milk besides other milks is a significant food and nutrient source for people in many countries, up to 55% of all milks produced in one country. However, the apparent daily supplies of animal protein and calcium per person from domestic production, according to world statistics, vary widely between countries, and are mostly deficient. The apparent milk productivity per goat is especially low and has much room for improvement (Table 2).

3. Comparative protein composition of goat milk

Data on the comparative composition of proteins and their components in the milk of goats and cows have been reviewed by Jenness (1980) and Haenlein (1996, 2001), documenting many unique differences between the two species, and showing a wide diversity due to genetics of different breeds within each species, influences of stage of lactation, feeding, climate, and subclinical mastitis. Compounding this diversity is the use of different testing methods and standards. It has been found that goat milk has a significantly higher dye-binding capacity per unit protein (1% more than cow milk) and a lower infra-red absorption (4% less than cow milk) (Grappin et al., 1979), making it necessary to use different calibration curves for each species to measure milk protein content. This has been confirmed in studies by Zeng (1996), when testing with cow milk standards resulted in 0.04% less fat and 0.27% less protein in goat milk.

Goat milk proteins are similar to the major cow milk proteins in their general classifications of α-, β-, κ-caseins, β-lactoglobulin, α-lactalbumin, but they differ in genetic polymorphisms and their frequencies in goat populations (Martin, 1993; Grosclaude, 1995; Jordana et al., 1996). The presence of the α-s-1-casein trait has been studied much in recent years, when it was discovered that it has six different types, A, B, C, E, F and "null" in goat milk. In cow milk, α-s-1-casein is the major α-s-casein. The "null" type or absence in some goat milk means that in different goats the major (α-s-casein is the α-s-2-casein variant, but which has different digestibility and cheese making properties (Remeuf, 1993). The differences in genetic types are due to amino acid substitutions in the protein chains, which in turn are responsible for the differences in digestibility, cheese making properties and flavors of goat milk products (Rystad et al., 1990), but the amino acid substitutions also enable the detection of even small amounts of adulteration with cow milk (Aschaffenburg and Dance, 1968; Amigo et al., 1989). In a study of κ-casein digestion, 27 differences in amino acid sequence between cow and goat milk casein macropeptides were found (Mercier et al., 1976). Peptides formed from goat milk casein by proteases tasted much less bitter than those from cow milk casein (Pelissier and Manchon, 1976). Casein micelles, the form of casein molecule suspended in goat milk, also differ markedly from cow milk in less complete sedimentation rate, greater β-casein solubilization, smaller size of micelle, more calcium and phosphorus, less solvation, and low heat stability (Jenness, 1980).

Average amino acid composition of goat and cow milk, as published in official USDA tables, shows higher levels of 6 of the 10 essential amino acids: threonine, isoleucine, lysine, cystine, tyrosine, valine in goat milk (Posati and Orr, 1976) (Table 3). Their comparative metabolic effects have not been studied much in goat milk, but this could aid in the interpretation of some of the empirical beneficial effects of goat milk in human nutrition. In studies with rats, which had malabsorption syndromes, it was found that goat milk improved the intestinal absorption of copper, which was attributed to the higher contents of cysteine (derived from cystine) in goat milk (83 mg/100 g) than in cow milk (28 mg/100 g) (Barrionuevo et al., 2002). Overall, the adult daily dietary nutrient recommendations for essential amino acids would be met equally or exceeded by a 0.5 l goat milk consumption compared to cow milk (NRC, 1968).

Table 3
Average amino acid composition (g/l00 g milk) in proteins of goat and cow milk (Posati and Orr, 1976)

	Goat milk	Cow milk	Difference (%) for goat milk
Essential amino acids			
Tryptophan	0.044	0.046	
Threonine	**0.163**	**0.149**	**+9**
Isoleucine	**0.207**	**0.199**	**+4**
Leucine	0.314	0.322	
Lysine	**0.290**	**0.261**	**+11**
Methionine	0.080	0.083	
Cystine	**0.046**	**0.030**	**+53**
Phenylalanine	0.155	0.159	
Tyrosine	**0.179**	**0.159**	**+13**
Valine	**0.240**	**0.220**	**+9**
Non-essential amino acids			
Arginine	0.119	0.119	
Histidine	0.089	0.089	
Alanine	0.118	0.113	
Aspartic acid	0.210	0.250	
Glutamic acid	0.626	0.689	
Glycine	0.050	0.070	
Proline	0.368	0.319	
Serine	0.181	0.179	

4. Comparative fat composition of goat milk

A much overlooked component in goat milk is its fat or lipid content. Average goat milk fat differs in contents of its fatty acids significantly from average cow milk fat (Jenness, 1980), being much higher in butyric (C4:0), caproic (C6:0), caprylic (C8:0), capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), linoleic (C18:2), but lower in stearic (C18:0), and oleic acid (C18:1) (Table 4). Three of the MCT (C6–C14) have actually been named after goats, because of their predominance in goat milk.

Capric, caprylic acids and MCT have become established medical treatments for an array of clinical disorders, including malabsorption syndromes, chyluria, steatorrhea, hyperlipoproteinemia, intestinal resection, premature infant feeding, non-thriftiness of children, infant malnutrition, epilepsy, cystic fibrosis, coronary by-pass, and gallstones, because of their unique metabolic ability to provide direct energy instead of being deposited in adipose tissues, and because of their actions of lowering serum cholesterol, inhibiting and limiting cholesterol deposition

Table 4
Average fatty acid[a] composition (g/100 g milk) in lipids of goat and cow milk (Posati and Orr, 1976)

	Goat milk	Cow milk	Difference (%) for goat milk
C4:0 butyric	0.13	0.11	
C6:0 caproic	0.09	0.06	
C8:0 caprylic	0.10	0.04	
C10:0 capric	0.26	0.08	
C12:0 lauric	0.12	0.09	
C14:0 myristic	0.32	0.34	
C16:0 palmitic	0.91	0.88	
C18:0 stearic	0.44	0.40	
C6-14 total MCT	**0.89**	**0.61**	**+46**
C4-18 total SAFA	**2.67**	**2.08**	**+28**
C16:1 palmitoleic	0.08	0.08	
C18:1 oleic	0.98	0.84	
C16:1-22:1 total MUFA	**1.11**	**0.96**	**+16**
C18:2 linoleic	0.11	0.08	
C18:3 linolenic	0.04	0.05	
C18:2-18:3 total PUFA	**0.15**	**0.12**	**+25**

[a] MCT: medium chain triglycerides; SAFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

(Schwabe et al., 1964; Greenberger and Skillman, 1969; Kalser, 1971; Tantibhedhyanangkul and Hashim, 1975, 1978; Alferez et al., 2001). Goat milk exceeds cow milk in monounsaturated (MUFA), polyunsaturated fatty acids (PUFA), and medium chain triglycerides (MCT), which all are known to be beneficial for human health, especially for cardiovascular conditions (Table 4). This biomedical superiority has not been promoted much in marketing goat milk, goat yoghurt and goat cheeses, but has great potential in justifying the uniqueness of goat milk in human nutrition and medicine (Babayan, 1981; Haenlein, 1992) for treating the various gastro-intestinal disorders and diseases, besides its value in alleviating cow milk allergies.

Fatty acid composition of goat milk fat also can be changed towards even more of the beneficial fatty acids by different regimes of feed supplementation to goats including changes of forage: concentrate ratios (Delage and Fehr, 1967a, 1967b; Alonso et al., 1999; LeDoux et al., 2002; Sanz Sampelayo et al., 2002). Goats fed a high level of pasture forage had higher milk fat contents of C4:0, C6:0, C18:0, C18:l, C18:3, C20:0, *iso*-, ante-*iso*-, and odd fatty acids, but lower values of C10:0, C12:0, C14:0, C16:0, and C18:2, than those fed the low levels of forage. However, high levels of alfalfa forage also produced the lowest contents of the less desirable *trans*-C18:1 fatty acids (LeDoux et al., 2002). The conclusion was that decreasing the fiber content and increasing the grain part in the goat daily ration would lead to higher contents of the undesirable *trans*-C18:1 fatty acid in milk. Manipulations of goat feeding regimes towards higher contents of beneficial unsaturated fatty acids in goat milk fat by feeding special feed supplements like protected fats can be used to “tailor make” “functional foods” and even further improve the nutritional value of goat milk (Sanz Sampelayo et al., 2002; Ebersdobler, 2000). Recently more “beneficial fat”, conjugated linoleic acid (CLA), has been identified as a potent anticarcinogen and is primarily provided to the human diet by dairy products (Ip et al., 1999; Hinders, 1999; Pfeuffer, 2000), but it has not been studied much in goat milk yet (Mir et al., 1999).

Branched-chain fatty acids have been studied in goat milk recently, because they lend characteristic flavors to dairy foods (Ha and Lindsay, 1993; Alonso et al., 1999). Implicated in goat-like flavors is 4-ethyloctanoic acid, which was present at 0.227 mg/g total fatty acids among 31 minor branched-chain fatty acids. Monomethyl-branched substitutions on C4 and C6 fatty acids are present only in goat milk and not in cow milk. A comparatively high number of minor branched-chain fatty acids is found in goat milk and the content of *trans*-C18:l fatty acids is significantly lower in goat milk under average feeding regimes than in cow milk, also a benefit for coronary heart disease risks.

Goat butter, ghee and related products with their even higher contents of MCT, unsaturated fatty acids and CLA than the original milk has not been studied much nor produced commercially. Yet here is a potent answer to the question asked earlier, why goat milk. Here is the potential to provide a goat milk product with specially beneficial and proven properties for human nutrition and health, besides its general food value to starving people and to connoisseurs. A better understanding of the essentiality of certain fatty acids in human food intake is emerging recently with the proposal of revising the US food intake recommendations (Willett and Stampfer, 2003). This supports the idea that goat butter would have new and not yet promoted human health benefits, because the proposal by

Willett and Stampfer (2003) clearly states that "some fats are healthy for the heart".

5. Other unique components in goat milk

There are a number of unique physiological and anatomical differences between goats and cows which translate into differences in composition of goat milk and its products (Haenlein, 1992, 1996, 2001). This was already recognized by the Goat Milk Task Force of the National Conference on Interstate Milk Shipments (NCIMS, USA) (Atherton, 1983) and lead to important decisions by this governing body of the US dairy industry towards setting separate standards for goat milk from cow milk for butter fat content minimum, solids-not-fat content, somatic cell count maximum, method for only nucleated cells in milk, lower freezing point level, different natural inhibitor test, different milk pasteurization test, validity of brucellosis ring test, detection of cow milk in goat milk, all of which had to insure fair market quality control regulations and practices for goat milk producers. Further comparative differences between goat and cow milk in contents of enzymes, minerals, vitamins, miscellaneous constituents and physical properties have been reviewed in detail (Jenness, 1980; Haenlein, 1980, 1996, 2001).

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