

Past, Present, and Future Perspectives of Small Ruminant Dairy Research¹

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ABSTRACT

The objectives of this paper are to review small ruminant dairy research in relation to the dimensions of the dairy goat and dairy sheep industries in the United States and the world. At least 10 countries depend on goats and sheep for between 30 to 76% of total milk supply. Leading among developed countries is Greece producing 178 kg milk per person per year with 61% from sheep and goats. Most developing countries need research, extension service, and public support to improve apparent productivity of goats and sheep. Domestic supply from all milk sources is <100 kg/person per year, and annual apparent yields average <100 kg of milk/goat, <50 kg of milk/sheep, which makes supplies of animal protein and calcium from domestic sources very low. Statistical data on goat and sheep production for United States are not available. The small population of DHIA tested US dairy goats averaged in recent years >700 kg of milk/goat per year, and some dairy sheep breeds may produce as much as 650 kg/yr. The need for more milk availability appears to be reflected in the dramatic increases of dairy goat populations during the last 20 yr: 52% for the world, 56% for developing, 17% for developed countries, while sheep populations decreased by 3% for the world, by 6% in developed, but increased 14% in developing countries. Research has been sparse on the unique qualities of goat and sheep milk compared with cow milk. Much development work by various agencies has been devoted to reducing mortality and improving feed supplies in harmony with the environment; this work is mostly published in proceedings of scientific meetings, often not in English. Results have shown in many cases that dairy goats and dairy sheep can be very profitable, even in developing coun-

tries with difficult climate and topographical conditions.

(**Key words:** dairy goats, dairy sheep, goat milk, sheep milk)

Abbreviation key: EAAP = European Association for Animal Production, FAO = Food and Agriculture Organization of the United Nations (Rome), GTZ = Deutsche Gesellschaft fuer Technische Zusammenarbeit (Bonn), HPI = Heifer Project International (Little Rock), IAEA = International Atomic Energy Agency (Vienna), ICAR = Indian Council of Agricultural Research (New Delhi), IDF = International Dairy Federation (Brussels), IDRC = International Development Research Center (Ottawa), IFS = International Foundation for Science (Stockholm), IGA = International Goat Association, ILCA = International Livestock Center for Africa (Addis Ababa), ILRI = International Livestock Research Institute (Nairobi), INRA = L'Institut National de la Recherche Agronomique (Paris), ITOVIC = L'Institut Technique de l'Elevage Ovin et Caprin (Paris), RDA = recommended daily allowances, SR-CRSP = Small Ruminant-Collaborative Research Support Program Title XII, USAID = United States Agency for International Development (Washington, DC.).

INTRODUCTION

This review on small ruminants, specifically milking small ruminants, intends to bring together the latest technical information on a segment of the US and world dairy industry, which receives undeservedly little research attention in the United States and in many other parts of the world. All too often it is assumed that technical knowledge from dairy cattle can be extrapolated down to the smaller size of dairy goats and dairy sheep, and that the extensive research with meat sheep is sufficiently applicable to dairy sheep and dairy goats. Most animal science textbooks have dealt only with dairy cattle, meat and wool sheep, but dairy goats and dairy sheep were usually only briefly mentioned, or not at all, as late as in presentations at the 1998 International Dairy Congress (Haenlein, 1980b, 1988; IDF Danish Nat. Comm., 1999).

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Translation of dairy cow data to apply to goats and sheep often is an oversimplification, but more often inappropriate and wrong. Many times it is not justified because of unique anatomy, physiology, nutrition, metabolism, and pathology of goats and sheep. Many aspects of goat and sheep milk products are also unique (Gipson et al., 1992; Haenlein, 1980a, 1987b; Haenlein and Devendra, 1983). The dominant presence of dairy cattle and their milk products makes it difficult for breeders and managers of dairy goat and dairy sheep enterprises to sustain a competitive niche in the market place (Redfern et al., 1985) and to receive sufficient research and promotional support. In terms of biological efficiency or "dairy merit" the high genetics level of milk production of dairy cows is easily matched by the high genetics level of milk production of dairy goats in some countries such as U.S.A., England, New Zealand, Israel, Switzerland. Economics of scale, however, favors the large dairy cattle over the small goats and sheep in labor costs. Thus cow milk products can be marketed at a much lower price without sacrificing profitability.

Dairy goat and dairy sheep industries are of significant economic importance to the national economy of many countries (Ayers and Foote, 1982; Devendra and Burns, 1983; French, 1970; Haenlein and Fahmy, 1999; Rubino and Haenlein, 1996; Santana et al., 1987). Dairy goats and dairy sheep are also critically important to the survival and well-being of large segments of populations, which often have no other alternatives for supplies of sufficient food, basic nutrition, and income (Haenlein, 1978b, 1987a, 1996a, 1998). For many people, and especially infants, the milk and dairy products from goats and sheep are also a medical necessity (Haenlein, 1992) as an alternative to cow milk. Such conditions have received very little medical research attention (Gurr, 1992, 1998), while they are supported by much anecdotal experience (Campbell and Marshall, 1975; Hachelaf et al., 1993; Haenlein, 1992, 1996; Razafindrakoto et al., 1993).

Gourmet cheeses and yogurt, milk powder, evaporated and UHT milk from goat and sheep milk have increasing appeal in affluent societies and are making significant financial contributions to the economy of some exporting countries (Gipson et al., 1992). National farm and cow milk quota policies have also caused the development of dairying with goats and sheep as an alternative enterprise to dairy cows. There is increasing interest in creating direct marketing of value-added products such as artisanal farmhouse cheeses, yogurt, kefir from goat and sheep milk (Boylan, 1989; Lu, 1987; Mills, 1989; Sahlu, 1999; Thomas and Rowe, 1998).

Many countries with organized governmental support and promotion of the dairy cattle industry, have dairy goat and dairy sheep industries, which exist, even

thrive, without such support, because of at least four reasons:

Goats and sheep provide home supply and self-sufficiency for families to avoid starving and malnutrition in protein, calcium, vitamins and energy. It has been noted that more people around the world drink goat milk than cow milk (Campbell and Marshall, 1975; Haenlein, 1981), and more people live on yogurt and cheeses from sheep and goat milk than cow milk, because they do not have enough money, or it is their tradition or preference.

Goat and sheep milk and their products are a medical necessity for many people as an alternative to cow milk. Food allergies and gastrointestinal disorders have been helped by goat and sheep milk in many anecdotal but poorly researched reports (Campbell and Marshall, 1975; Hachelaf et al., 1993; Haenlein, 1992; Razafindrakoto et al., 1993).

Steep mountainous terrain and desert regions can often only be managed and harvested by small ruminants (Haenlein, 1998).

Commercial dairy goat and dairy sheep enterprises depend financially on the willingness of upscale consumers to pay higher prices for tasty, traditional, or gourmet products (Redfern et al., 1985). Dairy goats and dairy sheep have evolved above "the little cow of the poor man." Even goat and sheep-rich developing countries may benefit from providing specialty foods to higher income people and nations. As more people and more countries become more affluent, the future value of dairy goats and dairy sheep should also rise, contrary to an old Wall Street Journal axiom that poverty and numbers of goats are positively correlated.

Economic Importance of Goat and Sheep Milk

The economic contributions of goat and sheep milk production in various countries are shown from FAO Production Yearbook data in Tables 1, 2, and 3 (Haenlein, 1996a). Dairy goat and dairy sheep farming is of significant importance to the national economy of more than a dozen countries. This is especially true in the Mediterranean area and includes developed countries like France, Italy, Spain, and Greece, which again proves that goat and sheep dairying is not necessarily synonymous with underdevelopment and poverty.

A major benefit from goat and sheep farming is derived in many countries from the production of meat (interests of religious and ethnic people such as Islam, Judaism, Orthodox Christian, Caribbean), fiber (mohair and cashmere), and skins. The emphasis of and selection for goat and sheep milk production and its products is often secondary, except in about two dozen countries (Tables 1 to 3) for reasons of climate (desert),

Table 1. Economic contribution of sheep milk in countries with significant sheep milk production.¹

	Sheep milk in % of all milk produced in country	World sheep milk in % of milk production
Syria	37	7
Afghanistan	37	3
Greece	35	8
Iraq	33	2
Somalia	25	2
Algeria	23	3
Iran	22	10
Sudan	14	6
Romania	12	5
Turkey	10	14
Bulgaria	9	2
Italy	6	8
France	4	14
Spain	4	4
10 Mediterranean countries	12	66

¹Haenlein, 1996a.

geography (mountains), or taste preference (traditional and gourmet). No statistical data are available worldwide on separate populations of dairy goats and dairy sheep compared with meat and fiber goats, and meat and wool sheep populations (FAO, 1998). Therefore, the data in Table 4 must be understood to include goats and sheep for meat, fiber, and skin production to varying degrees in different countries besides those for milk production. This is especially true for the United States, where government statistics are only available for Angora goat populations in a few states.

Table 2. Economic contribution of goat milk in countries with significant goat milk production.¹

	Goat milk in % of all milk produced in country	Goat milk in % of world milk production
Bangladesh	55	10
Somalia	51	4
Mali	43	2
Indonesia	29	2
Greece	26	4
Iran	24	9
Sudan	16	6
Algeria	13	1
Spain	7	4
India	4	22
Pakistan	4	6
Turkey	3	3
France	2	4
Italy	1	1
10 Mediterranean countries	3	18

¹Haenlein, 1996a.**Table 3.** Economic contribution of sheep and goat milk combined in countries with significant sheep and goat milk production.¹

	Sheep and goat milk in % of all milk produced in country	All milk/person per year, kg ²
Somalia	76	76
Greece	61	178
Bangladesh	56	15
Iraq	46	26
Iran	46	59
Afghanistan	44	27
Syria	42	99
Indonesia	40	3
Algeria	36	38
Sudan	30	132
Bulgaria	14	176
Turkey	13	171
Romania	13	145
Spain	11	167
China	10	7
Italy	7	194
France	6	457
10 Mediterranean countries	11	211

¹Haenlein, 1996a.²Includes all milk from cows, buffaloes, goats and ewes.

Worldwide goat populations have increased by 52% in numbers (Table 4), paralleling the 33% increased numbers of people. Sheep populations have decreased by 3%, which is reflecting the drastic market decline in demand for wool, and to a smaller degree for lamb meat, rather than for milk, cheeses, and yogurt from sheep milk. This is indicated by the declines in sheep numbers in traditional wool producing countries of the Americas (-24 and -19%), Australia, and New Zealand (Oceania, -17%; Table 4) (FAO, 1998). On the other hand, sheep numbers actually are increasing in Europe (+15%), Asia (+16%), and Africa (+28), indicating an interest in sheep in some countries, maybe for dairy purposes. Goat numbers are increasing greatly on each continent (+32 to +133%), again showing an apparent strong interest for more milk production. North and Central America had zero change during the last 20 yr, because no reliable data are available. Increases in numbers of dairy cattle (+8%; Table 4) reflect in the developing countries (+56%) the need for more milk for their growing urban people populations beyond what is contributed from goats and sheep. Decreases (-23%) in developed countries are due to the inverse correlations between increased productivity per cow and shrinking cow population numbers.

The need for more milk worldwide from whatever species is documented in Table 5. During the last 20 yr apparent milk production increases of dairy goats

Table 4. Population changes during the last 20 yr for goats, sheep, dairy cattle, and people.¹

	Goats		Sheep		Dairy cattle		People	
	1998	Ch ²	1998	Ch ²	1998	Ch ²	1998	Ch ²
World	700	+52	1064	-3	230	+8	5901	+33
Developing world								
Africa	204	+39	233	+28	37	+68	749	+56
Asia	439	+67	368	+16	71	+48	351	+36
S. America	25	+32	85	-19	40	+60	336	+40
Total	668	+56	686	+14	148	+56	1436	+47
Developed world								
N+Central America	13	0	16	-24	20	-5	472	+26
Europe	16	+33	141	+15	32	-36	508	+5
Oceania	1	+133	167	-17	6	+50	30	+67
Total	30	+17	324	-6	58	-23	1010	+15

¹In million (FAO, 1998).²Changes in percentages in populations since 1979 (FAO, 1985).

(+69%) exceeded those of dairy cows (+10%) worldwide, while dairy sheep (+2%) production needs much improvement. It must be kept in mind, however, that the reliability of statistics of production records varies greatly from country to country and is generally much better for dairy cow records than for those of dairy goats and dairy sheep.

Nutritional Benefits from Goat and Sheep Milk

Milk and dairy products from goats and sheep are very important for proper human nutrition, where cow milk is not readily available or affordable. In some countries more than one half or at least one third of all milk is supplied by goats and sheep (Table 3), which makes their contribution to sufficient protein and calcium nu-

trition of people very significant. Table 6 shows that this supply of protein and calcium is far from sufficient in many countries, even with large dairy goat and dairy sheep populations. The recommended daily intake of at least 60 g of animal protein and 800 mg of calcium per adult person is apparently not achieved in many countries. The data on protein supplies from animal sources (milk + meat) show that there is much dependency instead on plant protein sources (lower half of Table 6). The data on calcium supplies show the same situation, and some of the very low supply data identify countries with an apparent great shortage of milking goats and (or) milking sheep, and (or) with low milk productivity levels, while goats and sheep are kept more for the production of meat and fiber.

Table 5. Milk production changes from goats, sheep, and dairy cattle during the last 20 yr.¹

	Goats		Sheep		Dairy cattle		Total			
	1998	Ch ²	1998	Ch ²	1998	Ch ²	1998	Ch ²	G ³ %	S ³ %
World	12.2	+69	8.2	+2	466	+10	486	+11	2.5	1.7
Developing world										
Africa	2.6	+73	1.6	+60	18	+80	22	+78	11.7	7.2
Asia	6.9	+103	3.8	+12	72	+118	83	+108	8.3	4.6
South America	0.2	0	...	...	45	+88	45	+87	...	...
Total	9.7	+90	5.4	+23	135	+101	150	+96	6.5	3.6
Developed world										
N+C America	0.1	0	...	...	91	+20	91	+20	...	...
Europe	1.8	+12	2.7	-23	154	+3	158	+5	1.1	1.7
Oceania	...	...	...	...	21	+75	21	+75	...	...
Total	1.9	+12	2.7	-23	266	+12	270	+11	1.1	1.7
USA	...	...	...	...	71	+22	71	+22	...	...

¹Million MT (FAO, 1998).²Changes in % in milk production since 1979 (FAO, 1985).³G = Goat milk in percentage of total milk from all species; S = sheep milk in percentage of total milk from all species (FAO, 1998).

Table 6. Supplies of calcium (mg/person per day) and protein (g/person per day) to people in leading goat and sheep milk producing countries.¹

	Animal sources		Total supplies	
	Calcium	Protein	Calcium	Protein
France	966	78	1179	116
Somalia	796	17	939	44
Greece	683	59	1033	114
Italy	604	58	863	109
Bulgaria	604	40	801	84
Spain	529	61	785	104
Romania	522	40	748	90
Sudan	438	22	605	65
Algeria	416	19	587	76
Mongolia	368	47	463	69
Syria	337	18	634	82
Pakistan	337	18	558	56
Mexico	303	31	467	79
Brazil	297	27	479	66
World	255	25	467	71
Turkey	206	26	471	100
India	195	10	471	58
Mali	96	15	383	64
Indonesia	54	9	226	60
Iran	?	16	?	74
China	40	16	236	67
Afghanistan	?	10	?	43
Ethiopia	?	8	?	51
USA	724	74	1052	113

¹Protein data from FAO (1994); calcium data from FAO (1990).

This situation becomes evident when the annual FAO Production Yearbook data for goat and sheep milk are converted to apparent productivity per animal per year (1000 MT divided by 1000 head) (Table 7), just as the FAO data for cow milk are listed after the same conversion for apparent productivity per cow per year (FAO, 1998, p. 212–214). One must admit that these productivity data per animal per year are “apparent,” because the FAO data do not clearly identify those percentages of the cow, goat, or sheep populations that are milking females and are kept mainly for milking purposes. Nevertheless, in the absence of better data, they do document important shortcomings in production of milk in certain countries and the need for improvement programs. Some countries do have low animal productivity in terms of kg of milk/head per year as, for instance, those in the lower half of Table 7. Interest in selection of high producing dairy animals either does not exist compared with the greater interest in meat and wool production, or high milk productivity is not feasible for reasons of climate, lack of feeds, and money for purchased feeds. On the other hand, the data in the upper part of the table tend to identify those countries where a major part of their goat and sheep populations are truly dairy oriented, such as in France, Greece, Italy, Spain, Bulgaria, Romania, Ukraine, and Iran.

Nutrient supply from goat and (or) sheep milk is very valuable in combating under- and malnutrition of people in poor areas and countries. Table 8 shows that goat and sheep milk can even be superior to cow milk in equal meals. The supply of two glasses (1/2 L) of milk or cheese or yoghurt equivalent from goat milk will provide up to 94% of recommended adult daily dietary allowances (RDA) of essential amino acids, 83% of calcium, 78% of riboflavin, and other minerals and vitamins to a lesser degree, while supplies from cow milk are up to 81, 74, and 89%, respectively. The supply from sheep milk is even more impressive, 162, 121, and 200%, respectively. Also, the supply of essential fatty acids, the critically important mono-unsaturated and medium chain fatty acids are in greater amounts from goat, and especially from sheep milk, than from cow milk. No RDA seem to have been established for these fatty acids. While the milk contents for amino acids and minerals are fairly stable, the contents of fatty acids can be greatly varied by different feeding regimes of the animals, pasture versus grain supplements, different roughages, different fats and fat contents in the grain supplement, and different roughage to grain ratios. This can and should be better exploited in the promotion of goat and sheep milk having valuably different nutritional properties, even being so called “functional foods” (IDF Danish Nat. Comm., 1999).

Uniqueness of Goats and Sheep

Extensive comparisons in suitability of goats, sheep, and cattle for tropical environments were presented at the 3rd International Conference on Goat Production and Disease, 1982 (McDowell and Woodward, 1982) and at other symposia (Devendra, 1993, 2000). The summary in Table 9 shows that goats, sheep, and cattle are physiologically as well as morphologically different and unique in many traits. Among 56 traits of adaptability compared, goats would be superior in 16 over cattle and 18 over sheep; sheep in 20 over goats (McDowell and Woodward, 1982). However, fat tail sheep were apparently not included in the comparison, nor were proportional differences allowed for European, crossbred, tropical, and dual-purpose cattle, goats and sheep. In feeding activities, it has been reported that goats, sheep, and cows spend 38, 80, and 76% of their daily time grazing, while 53, 10, and 8% for browsing, respectively (Haenlein and Devendra, 1983). Goats may walk 10 km per day foraging, compared with 6.5 km for sheep, and 5.6 km for cows. Goats can survive on much less frequent water intake in 3 d than sheep or cows.

There are several well-researched and published physiological differences, making goats and sheep unique in many aspects (Elsheikh, 1999; Haenlein,

1980a, 1987b; Haenlein and Devendra, 1983; IDF, 1986, 1996). Nutrient requirements between the three species differ depending on whether they are based on direct relationships of BW, body surface (live weight to the 0.66 or 0.75 or 1.0 power), or direct experimentation. As a result, BW relationships underestimate nutrient requirements, while body surface relationships may overestimate them. The best relationship between 600-kg cows and 60-kg goats is not 10:1 but rather 7.5:1 (Haenlein and Devendra, 1983).

Mineral metabolism differs between the species for several elements (Ramirez et al., 1991). Goats will tolerate more than 300 mg of molybdenum/kg of DM daily feed intake, sheep only one tenth at 30 mg/kg, and cattle will suffer diarrhea already at 10 mg/kg. Copper toxicity symptoms occur in sheep at 10 to 20 mg of Cu/kg of feed intake, while cattle and goats tolerate and may even require up to 100 mg/kg. Iodine in feed is transferred at the rate of 22% into milk by goats, while cows transfer only 8%. Colostrum from goats may contain 10 times as much iodine than colostrum from cows. Goats are also more sensitive to low iodine supplies than sheep and cows, and have a higher basic iodine requirement. Magnesium levels in blood plasma are affected by potassium supplementation in sheep but apparently not in goats. Newborn goats have very low

iron reserves in liver and blood in contrast to calves and lambs.

Milk compositions differ between the species (Haenlein, 1980a, 1996a; Haenlein and Ace, 1984). Sheep milk is much higher in fat and SNF contents than goat or cow milk, making it ideal for cheese and yoghurt production. Goat milk is similar to cow milk in gross composition, but lacks beta-carotene, agglutinin and has less alpha-s-1-casein, citric acid, sodium, iron, sulfur, zinc, molybdenum, ribonuclease, alkaline phosphatase, lipase, xanthine oxidase, N-acetylneuraminic acid, orotic acid, pyridoxine, folate, vitamins C and B12, lower freezing point and pH. Goat milk is usually higher in calcium, potassium, magnesium, phosphorus, chlorine, manganese, short and medium chain fatty acids, vitamins A and D, nicotinic acid, choline, and inositol. Fat globules are smaller to a much larger proportion, they cream up only very slowly over several days, and their membranes are very fragile, liberating easily lipase, then flavorful fatty acids, and causing rancidity and off-flavors readily. Goat milk is more easily digested because of the smaller size fat globules and different casein types, but therefore often has a softer curd in cheese making and a lower yield than does cow milk. Goat and cow milk have about the same contents of carnitine, but sheep milk is about eight times higher. Glycerol

Table 7. Apparent milk productivity per goat or sheep in countries with significant tonnage of goat or sheep milk production compared with their numbers of goats or sheep.¹

	Goats				Sheep		
	Milk kg/goat per yr	Milk 1000 MT	Goats mil.		Milk kg/sheep per yr	Milk 1000 MT	Sheep mil.
France	400	480	1.2	Greece	71	670	9.5
Ukraine	294	206	0.7	Italy	70	759	10.9
Bulgaria	168	162	1.0	Iran	67	463	6.9
Russia	125	200	1.6	Bulgaria	39	110	2.8
Spain	121	350	2.9	Romania	38	340	8.9
Italy	115	150	1.3	Syria	37	515	14.0
Greece	78	460	5.9	Somalia	32	430	13.5
Syria	73	80	1.1	Turkey	27	826	30.2
Algeria	47	145	3.1	France	24	243	10.3
Bangladesh	40	1328	33.5	Iraq	23	155	6.9
Iraq	35	53	1.5	Bangladesh	18	22	1.2
Somalia	31	390	12.5	Mali	15	89	6.0
Sudan	31	1151	37.3	Ukraine	14	23	1.7
Turkey	30	249	8.4	Afghanistan	14	201	14.3
India	26	3128	120.6	Spain	12	300	24.5
Mali	20	168	8.6	Algeria	11	180	16.8
Afghanistan	19	41	2.2	Sudan	11	461	42.4
Pakistan	17	818	48.6	China	10	1140	118.1
Indonesia	15	232	15.2	Pakistan	2	57	32.4
Mexico	15	123	8.6	Indonesia	2	96	53.0
Iran	15	398	27.0	Ethiopia	2	58	23.3
Brazil	11	141	12.6	Mongolia	1	20	14.2
USA	?	?	?	USA	?	?	?

¹Adapted from FAO, 1998, p. 215–216.

Table 8. Nutrient supply from three alternative sources of milk (1/2 L) compared with percentage of recommended adult daily dietary allowances (RDA).¹

	Goat milk		Sheep milk		Cow milk		RDA
	Supply	% RDA	Supply	% RDA	Supply	% RDA	
Essential amino acids (g)							
Tryptophan	0.2	40	0.4	80	0.2	40	0.5
Threonine	0.8	80	1.4	140	0.8	80	1.0
Isoleucine	1.1	79	1.7	121	1.0	71	1.4
Leucine	1.6	73	3.0	136	1.6	73	2.2
Lysine	1.5	94	2.6	162	1.3	81	1.6
Methionine	0.4	18	0.8	36	0.4	18	2.2
Cystine	0.2	?	0.2	?	0.2	?	?
Phenylalanine	0.8	36	1.4	64	0.8	36	2.2
Tyrosine	0.9	?	1.4	?	0.7	?	?
Valine	1.2	75	2.2	138	1.1	69	1.6
Minerals (mg)							
Ca	666	83	968	121	594	74	800
Mg	70	35	92	46	68	34	200
P	551	69	790	99	466	58	800
K	1018	?	682	?	756	?	?
Vitamins (mg)							
Thiamine	0.3	38	0.3	38	0.2	25	0.8
Riboflavine	0.7	78	1.8	200	0.8	89	0.9
Niacin	1.4	10	2.1	15	0.4	3	14
Essential fatty acids (g)							
C18:2 linoleic	0.6	?	0.9	?	0.4	?	?
C18:3 linolenic	0.2	?	0.7	?	0.2	?	?
Monounsaturated fatty acids							
C16:1 palmitoleic + C18:1 oleic	5.3	?	8.4	?	4.6	?	?
Medium chain fatty acids							
C6:0 caproic + C8:0 caprylic + C10:0 capric + C12:0 lauric	2.8	?	4.6	?	1.4	?	?

¹Adapted from Posati and Orr, 1976; Haenlein, 1996a; average composition of goat milk: 12.97% total solids, 3.56% protein, 4.14% fat, 4.45% lactose, 0.82% ash; sheep milk: 19.30% total solids, 5.98% protein, 7.00% fat, 5.36% lactose, 0.96% ash; cow milk: 12.01% total solids, 3.29% protein, 3.34% fat, 4.66% lactose, 0.72% ash.

ethers are much higher in goat than in cow milk, of significance to the nursing newborn. The lower contents of orotic acid in goat milk are of value for the prevention of fatty liver syndromes. Differences in milk composition between the species need much more research to better understand and utilize their consequences in processing yogurt and cheese, although these characteristics are known to practitioners to some extent. The facts of unique differences can be powerful in promoting dairy goats and dairy sheep as justifiable and valuable complements to the dairy cow industry.

One of the differences between goat, sheep, and cow milk is of great economic importance to the farmer. It is the SCC, which is a combination of leukocyte cells and alveolar cell fragments in milk. It is measured as a quick test for the absence of clinical and subclinical mastitis and is a widely applied health quality standard and criterion to accept or reject a certain milk shipment for commercial sale (Haenlein, 1986, 1987b, 1999;

Haenlein and Hinckley, 1995). Besides the obvious difference of only two udder halves for goats and sheep compared with cows, the less obvious anatomical difference is the small udder cistern volume in ewe udders, compared with the relatively medium volume in cow udders and the large volume in goat udders, and the much tighter diameter of the teat sphincter of goat udders. Milk secretion is also very different, being apocrine in goats and merocrine in cows (Park and Humphrey, 1986). Apocrine secretion includes the loss of part of the secretory gland cell due to the pinching-off of the secretion-filled end of the gland cell, but leaving the nucleus and most of the cytoplasm to recover and repeat the secretion process. Merocrine secretion in contrast leaves the secretory gland cell intact (Jones et al., 1949). The apocrine secretion type in goats means that their milk contains normally high levels of cell fragments, which are counted under present routine laboratory methods usually as somatic cells, to be indicative

of mastitic conditions. Yet, these cell fragments in goat milk are not nucleated and have nothing in common with leukocytes nor are they indicative of clinical or subclinical mastitis. This type of apocrine milk secretion of goats is not widely known. It needs more research and extension education to protect goat farmers from discrimination by the application of the cow milk standards, which have been found to be unreliable and inappropriate for goat milk (Atherton, 1992; Maisi, 1990; Poutrel and Lerondelle, 1983). The situation of ewe milk secretion has been researched even less.

Research Publications—Past

For many years, the nutrition, physiology, product technology, and management of goats was considered similar to that of sheep and by extrapolation of BW to

Table 9. Relative comparison between goats, sheep, and cattle in environmental adaptation.¹

	Goats	Sheep	Cattle
Feeding habit	browsing	grazing	grazing
Forage preference	selective	not selective	not selective
Digestive rate	rapid	intermediate	slow
Use of poor feed	better	good	poor
Protein efficient	high	less	less
DMI/body size	high	medium	low
NE requirement/d	1.23 Mcal	1.23	1.72
ME requirement/d	2.19 Mcal	2.20	2.87
TDN requirement	0.6 kg	0.6	0.8
CP requirement ²	86 g	89	87
Water economy	efficient	less ³	much less
Dystocia	little	more	more
Ease of AI	less	less	more
Puberty	younger	younger	older
Generation interval	1 yr	1 yr	3 yr
Litter size	1.6	1.1	1
Heat tolerance	more	medium	less
Cold tolerance	less	more	more
Wet tolerance	less	more	more
Body surface/size	more	more	less
Muscle fat	less	more	more
Subcutaneous fat	less	more	more
Renal fat	more	less	less
Tail fat	none	much ⁴	none
Milk yield/size	high	low	medium
Fat yield/size	high	medium	low
Protein yield/size	high	medium	low
Milk fat %	medium	high	low
Milk protein %	medium	high	low
Persistency	high	high	low
Lactation	long	short	long
Let-down rate	fast	medium	slow
Milk efficiency	high	low	high
Labor cost	high	high	low
Production cost	high	high	low

¹McDowell and Woodward, 1982.

²Net energy, metabolizable energy, TDN, and crude protein requirements are from NRC bulletins for goats, sheep and dairy cattle (Haenlein and Devendra, 1983; NRC, 1981, 1985).

³Exception fat-tail sheep.

⁴Tail fat only in specific fat-tail breeds.

cows. Most animal science textbooks dealt extensively with cattle, sheep, horses, pigs, poultry, but not goats (Acker and Cunningham, 1960; Armsby, 1917; Cullison, 1975; Morrison, 1957; Peterson, 1950). Goats and their needs were usually dismissed with one short paragraph, stating that:

- not much is known nor published about goats,
- feeding and treating goats like small cows or sheep is generally sufficient,
- goats are not farm animals but pets in some of the countries from which the textbooks originated, or goats are animals that destroy the environment, and therefore do not deserve scientific treatment.

This was the past, up until the 1970s. Then, however, began a new era of recognition lead by a few voices, which have since then caused many new publications of meeting proceedings, symposia, and congresses around the world. They were supported strongly by organizations and agencies with philanthropic concerns, such as the Winrock Rockefeller Foundation (Glimp and Fitzhugh, 1977), the FAO (French, 1970), United States Agency for International Development (**USAID**), International Goat Association (**IGA**), International Dairy Federation (**IDF**), International Foundation of Science (**IFS**), Deutsche Gesellschaft fuer Technische Zusammenarbeit (**GTZ**), International Livestock Center for Africa (**ILCA**), International Livestock Research Institute (**ILRI**), and International Development Research Center (**IDRC**) (Aboul-Naga, 1988; Devendra, 1986, 1989; CAST, 1982; Singh and Sengar, 1990), just to name a few. Several persons also need to be recognized, who were convinced of the importance of small ruminants, especially dairy goats, in those early days. They proposed and documented that goats can significantly contribute to better feeding the growing human world populations, and they bucked the science establishment, which had not considered so far that research money was well invested in goat research. Much credit must be given to C. Devendra (Malaysia), S. N. Singh (India), O. P. S. Sengar (India), C. Gall (Germany), N. S. Raun (USA), J. C. LeJaouen (France), W. C. Foote (USA), T. A. Steine (Norway), K. L. Sahni (India), A. S. Demiruren (Italy), R. T. Wilson (Ethiopia), B. Veinoglu (Greece), J. Boyazoglu (Greece), P. Morand-Fehr (France), S. K. Jindal (India), M. Anke (Germany), A. Mowlem (U.K.), J. M. Corteel (France), and A. Shkolnik (Israel), an incomplete list of leaders, who made a real impact with their publications and conference presentations.

The 1st International Goat Congress was held in London, UK, 1964, but it was the 2nd Congress in Tours, France, 1971 (Le Jaouen and Disset, 1971) that mobilized the attention of researchers from 23 countries

Table 10. Distribution of research articles in leading international dairy science journals by goat and sheep, and by major subject areas.^{1,2}

	Total number	Goats %	Sheep %	Goat + Sheep %
J. Dairy Sci. 1988 to 1999	4699	1.7	1.6	
Small Rumin. Res. 1988–99	1285	55.2	49.6	
1997–99	407	46.7	56.3	
Management		12.1	7.9	
Nutrition		18.9	24.9	
Reproduction		17.9	22.3	
Physiology		15.8	12.2	
Veterinary		18.0	16.2	
Genetics		4.7	7.8	
Meat, fiber		4.7	7.0	
Milk, cheese, yogurt		7.9	1.7	
CAB 1992 to 1993 ¹				
Management				4.5
Nutrition				21.3
Reproduction				17.8
Veterinary				39.7
Genetics				5.9
Meat, fiber, milk				10.8
Animal Breeding Abstracts 1964–70 ²	4000/year			1.0

¹CAB = All articles on goats and sheep in 1992–93 (Morand-Fehr and Boyazoglu, 1999).

²Le Jaouen and Disset, 1971.

around the world to the importance of goats in fighting world hunger. During the previous 20 yr the world goat population had increased to 377 million head, by 20% in Africa, Latin America, Far East Asia, by 11% in Near East Asia, but decreased by 36% in Europe, including a few European countries down to almost zero. At the same time, goat milk made up 65% of all domestic milk production in Saudi Arabia; >40% in Iraq, Libya, Nigeria, and Mauritania; and 23% in Greece. During the 7 yr (1964 to 1971) since the 1st International Goat Congress in London, the research literature on goats, at least in English, was still stifled by bias and shortage of funding (Table 10). However, under the leadership of C. Gall and J. C. Le Jaouen at this 2nd International Goat Congress, a world committee for the organization of goat breeding was formed to promote the coordination of research and information between countries and to assure recurring International Conferences every 3 to 4 yr. Recommendations made by this congress were visionary and included a call to:

- end the negative attitudes towards goats,
- form an international center for education in goat production,
- establish an information bank and support information exchange,
- promote research on industrial transformation of milk, meat, skins,
- prioritize research on goat milk and its technology,
- generate data for objective breeding policies,

- require FAO to join by special representation,
- set up programs of goat development.

Many of these recommendations were eventually accomplished, but not as soon as envisioned by this 2nd Congress. It took 10 yr, not the proposed 3 to 4 yr for a next international congress to be convened again in Tours, France in 1981, and the published proceedings again were mostly in French (Morand-Fehr et al., 1981), limiting their worldwide distribution and use. By now the world population of goats had increased from 377 million in 1971 to 450 million head in 1981, and a beginning of more direct research attention to goats was noted, because goats were considered important for at least three reasons:

- its production potential relative to body size. This called for new research in the nutrient requirements, metabolism, and proper feeding according to the unique behavioral characteristics.
- its superior ability to digest coarse forages from shrubs and bushes, especially in dry and humid tropical regions. This called for new research into its meat, mohair and cashmere producing capabilities, which are important in countries with difficult climatic and topographical conditions.
- its milk production problems and benefits, which have not received much published research attention so far.

Credit must be given to a number of goat-oriented conferences, which preceded the new era of the 1980s and 1990s (Haenlein, 1978a, 1980c). Several agencies and countries were becoming interested in sponsoring the spread of scientific information on dairy goats and dairy sheep (Table 11), because a substantial resource literature existed (Haenlein, 1980b), although in widely scattered often non-English language and trade publications. An international Sub-Committee on Goat Nutrient Requirements was commissioned by the US National Research Council and an authoritative bulletin, refereed internationally, was published in 1981 from a bank of 2762 goat research articles (NRC, 1981). Many of the sources were in German, French, Norwegian, Greek, Turkish, Spanish, Italian, Russian languages, consisting of 347 titles on nutrient requirements, 469 on nutrition and feeds, 643 on milk composition and production, 121 on products of dairy, meat and fiber, 427 on management, 755 on breeding and health.

The time was ripe for a most comprehensive 3rd International Conference on Goat Production and Disease at the University of Arizona, Tucson, for 5 d in 1982 (Ayers and Foote, 1982). This conference included 70 invited speakers, five plenary sessions, 14 symposia, eight workshops, and 325 original individual contribu-

ted papers from 40 countries, besides exhibits of available publications and goat related products from sponsors of the conference. Although simultaneous translation was provided for foreign participants at the conference, the proceedings were entirely in English, thus disseminating for the first time the wealth of international goat research information into English.

At this conference the IGA was formally constituted with an international board of directors to assure continued international cooperation and coordination of research, and the convening of regular follow-up international goat conferences in 4- to 5-yr intervals in different parts of the world where goats are important. An International Journal of Sheep and Goat Research was also established as a private effort in conjunction with the US Dairy Goat Journal, a leading monthly trade magazine from Tucson, Arizona. Experience showed that this was financially not viable after a few years, because the subscription base in North America was small and internationally unable to generate enough money without subsidies. Fortunately, the newly existing IGA made successful negotiations with the world's leading animal science publisher, Elsevier, in The Netherlands for the founding of an IGA-sponsored international Small Ruminant Research journal in 1987 (Santana et al., 1987).

This journal appeared first quarterly but is now well organized on a monthly basis. Table 10 shows that this journal was very much needed not only to bring together research on goats, sheep, and other small ruminants, but to provide researchers a publication outlet for their work, which is essential for academic recognitions in their careers and promotions.

Research—Present Status

Since its first issue in 1988, the Small Ruminant Research journal has published 1285 peer-refereed papers, with 55% devoted to goats and 50% to sheep (some are goat and sheep combined) (Table 10). During the same 10-yr period, the US *Journal of Dairy Science* published among 4699 papers 2% covering goat and 2% dairy sheep topics. The distribution of areas covered in the Small Ruminant Research journal shows a dominance of nutrition, reproduction, and veterinary papers for goats as well as for sheep, similar to the distribution found in other surveys (Morand-Fehr and Boyazoglu, 1999). It seems that much needed research on goat and sheep products, especially dairy not only is still in relatively small numbers or is published elsewhere and not brought into the main arena of IGA and the Small Ruminant Research journal. It appears that efforts in higher and better productivity are the main research interest, while research in marketing and product im-

Table 11. Early evolution of goat-oriented conferences.¹

Year	Event and location
19??	1st International Congress on Goat Husbandry, ?
1921	2nd International Congress on Goat Husbandry, Wageningen
1930	3rd International Congress on Goat Husbandry, Antwerp
1956	Int. Congress Animal Reproduction & AI, Cambridge
1961	International Congress Animal Reproduction & AI, Hamburg
1964	International Congress Animal Reproduction & AI, Trento
1968	International Congress Animal Reproduction & AI, Paris
1972	International Congress Animal Reproduction & AI, Munich
1976	International Congress Animal Reproduction & AI, Krakov
1964	FAO Seminar on Goat Raising Policies, Rome
1964	1st International Conference on Goat Husbandry, London
1971	2nd International Conference on Goat Husbandry, Tours
1972	Int. Symposium Dairy Goats & Sheep, Tel Aviv
1972	World Congress Animal Production, Madrid
1973	World Congress Animal Production, Melbourne
1976	1st Annual Dairy Goat Symposium, Urbana, IL
1976	Symposium Sheep & Goat Practitioners, Fort Collins, CO
1976	Symposium Smallholder Livest. Prod., Shahalam, Malaysia
1976	Role of Sheep & Goats in Agr. Dev., Winrock, AR
1977	Symposium Dairy Goats, ADSA Ann. Mtg., Ames, IA
1977	Symposium Mgt. Repro. Sheep & Goats, ASAS, Madison, WI
1977	Potential World Forages Rumin. Prod., Winrock, AR
1978	Role Rumin. in Support of Man, Winrock, AR
1978	Symposium Internat. Progr., ADSA & ASAS, East Lansing, MI
1979	Int. Conf. Dev. Goats in Asia, Karnal, India
1979	Int. Symposium Dairy Goats, ADSA Ann. Mtg., Logan, UT

¹Haenlein, 1980b.

Table 12. Listings in major abstract journals of goat and caprine titles.¹

Years	Source	Total number	Titles/yr
1969–1987	BIOSIS, Philadelphia	1111/18 yr	62/yr
1979–1987	AGRICOLA, USDA	560/8 yr	70/yr
1967–1987	CAB, U.K.	1214/20 yr	60/yr
1967–1987	Chemical Abstracts	863/20 yr	43/yr
1966–1987	MEDLINE	70/21 yr	3/yr
	MEDLINE—pediatrics	20/21 yr	<1/yr

¹Haenlein, 1988.

provements, and better economics of producers are lagging behind (Table 12).

A directory of current research projects on goats and sheep worldwide (King, 1988) lists comprehensively on 271 pages the personnel, titles, objectives, and references of each project in 56 countries. Summary sheets cover goat projects on four pages, but sheep projects on 13 pages, reflecting again the original and still hard to eradicate dominance of research on wool and meat sheep, but not much on dairy sheep or dairy goats. Into this void, an upsurge of proceedings publications of technical conferences on goats rather than journal publications has stepped. The explanation maybe a faster turnaround from writing to publishing and an easier referee process. Nonetheless the results of new goat research via this medium are impressive, although copies are often hard to obtain except by personal appearance at the respective conferences, with the exception of the series of International Goat Conferences sponsored by IGA (Acharya and Lokeshwar, 1992; Ayers and Foote, 1982; Holst, 1996; Santana, 1987; Gruner and Chabert, 2000).

Major efforts of stimulating and coordinating research internationally were directed by USAID, GTZ, Small Ruminant-Collaborative Research Support Program Title III (**SR-CRSP**), IFS, Food and Agriculture Association (**FAO**) and others, resulting in many conference proceedings (Becker et al., 1995; Blond, 1983; Devendra, 1986, 1989, 1993, 1999a, 1999b; European Association for Animal Production (**EAAP**), 1983; El Aich et al., 1995; Haenlein, 1987a), especially in the Mediterranean area, India and the Far East, where the majority of goats, dairy or multipurpose, are found. At the 4th International Conference on Goats in Brazil, 1987 (Santana, 1987), 20% of all paper presentations were contributed by Indian scientists. With 90 million goats, India then had more dairy goats than any other country, including China, with similar total numbers, but not dairy rather than Cashmere goats (Acharya and Lokeshwar, 1992; Holst, 1996). India was also leading institutionally with an entire research station at Makhdoom near Agra, within their Indian Council of Agricultural Research (**ICAR**) system, devoted entirely to goat

production research, and at Karnal partially to goat milk technology. At the R.B.S. and U.P. Colleges at Agra and Varanasi, a massive study had started in 1974 on the combining abilities of desirable characters of important goat breeds for meat and milk (Singh and Sengar, 1990). The detailed interim reports contributed significantly to the 1st NRC publication on Nutrient Requirements of Goats (NRC, 1981).

Technical books on goats with emphasis on dairy production also began to appear (Baker, 1983; Baker and Miller, 1984; Considine and Trimberger, 1985; Coop, 1982; Devendra and Burns, 1983; Ensminger, 1980, 1981; Gall, 1981, 1996; Guss, 1977; Haenlein, 1950; Haenlein and Ace, 1984; Jindal, 1984; Johnson and Oliveira, 1990; Mackenzie, 1970; Mowlem, 1988; Munoz and Tejon, 1980; Paacock, 1996; Quittet, 1980; Rubino, 1990; Schmid, 1946; Speedy, 1992; Thedford, 1983), and became widely distributed, dispelling the old complaint by scientists and extension workers that “there is no information on goats.”

A focus on dairy sheep occurred only in French, Italian, and Spanish publications by EAAP, L’Institut National de la Recherche Agronomique-L’Institut Technique de l’Elevage Ovin et Caprin (**INRA-ITOVIC**) (King, 1988; Morand-Fehr et al., 1995; Munoz and Tejon, 1980) and Greek scientists (Anifantakis, 1991; IDF, 1986, 1996). The Alfa-Laval milking machine company published an excellent book on dairy sheep in 1981 and discussed 21 recognized breeds of dairy sheep (Kervina et al., 1981). In 1982, the first edition of a practical book on sheep dairying was published by O. Mills (1989), which was new, timely, and widely recognized. It is now in its second edition and was derived mostly from British experiences of a revival of sheep dairying when British dairy cow farmers were trying to overcome milk quota-induced income problems. A major conference on sheep production in Asia, held in the Philippines in 1988 (Devendra and Faylon, 1989), dealt only with aspects of meat and wool production, as if milk production by ewes had no importance or scientific merits. Table 1 shows that in many Asian countries then, like Syria, Afghanistan, Iraq, and Iran, milk production from sheep is and was very significant to their national economies. North America, however, has had no dairy sheep and their special nutritional requirements were totally ignored in the technical literature, including the authoritative NRC 6th revised edition of Nutrient Requirements of Sheep (NRC, 1985). Not until veterinary regulations and semen and embryo technology made importations of dairy sheep possible by the end of the 1980s (Boylan, 1989b; Terrill, 1977; Thomas and Rowe, 1998), did sheep dairying also begin in the United States. There were two incentives. The United States imported annually 20,000 tons of ewe

milk cheeses at that time (Boylan, 1989a); US wool and meat sheep, Suffolk, Rambouillet, Targhee, Dorset, Finn, were found to yield only between 65 to 85 L of milk/yr, with about 130 d lactation length, while internationally known dairy sheep breeds, East Friesian, Awassi, Sarda, Lacaune, Chios could produce up to 650, 500, 250, 200, 200 L/yr in lactations of 260, 250, 240, 210, 260 d length, respectively (Boylan, 1989a).

Sheep milk production systems differ, however, from goat milk production systems (Boylan, 1989b). Milk record keeping is not only less than on goat farms, but also difficult to compare because of the different production systems. United States dairy goat production records averaged 720 L of milk/yr in 310-d lactations in 1981 for about 1% on official record keeping of the estimated US dairy goat population of 1 million (Haenlein, 1978b, 1981, 1996b). This compares with an annual yield of 200 L worldwide (CAST, 1982). The differing production systems in various countries are:

- lambs are weaned at 1 mo and milking proceeds for 5 more months, or
- ewes are partially milked from 1 mo after lambing for 5 more months, or
- ewes are partially milked until weaning at 2 mo and milking proceeds for 4 more months, or
- lambs nurse for 3 mo and ewes are milked for 1 more month, or
- milking proceeds right after lambing for 8 mo, or
- milking after weaning at 1 mo may extend for 8 more months with three times per day milking, or
- goat milking proceeds usually after weaning at 2 mo for another 8 mo, or
- transhumance often dictates milking procedures different from those for stabled animals, or
- goats will tolerate once a day milking with less milk loss than ewes, or
- goats will also milk continuously for 2, even 3 yr without kidding and with high persistency, thus providing winter milk without interference from seasonal breeding.

Among the many new proceedings publications, there were also reports from development projects, which included economic studies (Haenlein, 1978b; Raghavan et al., 1990; Rathore, 1993; Redfern et al., 1985; Sagar, Vidya and Kanta Ahuja, 1993) documenting more convincingly than ever why small ruminants are not only important but also profitable. The Indo-Swiss Goat Development and Fodder Production Project (Rathore, 1993; Sagar, Vidya and Kanta Ahuja, 1993) published very interesting survey data, which are probably typical for many other areas in the world. In asking for reasons for goat keeping, the majority of the 1030 goat households in the eight districts of the state of Rajasthan

answered that it was mainly the home consumption of milk and also the sale of kids (Sagar, Vidya and Kanta Ahuja, 1993) (Table 13). Other reasons played a minor role. However, considering the greatly increased numbers of goats around the world and the fear by political administrators that there may follow environmental dangers, another survey asked about reasons for increasing goat herd size. Between 22 and 59% of the 1030 goat households in the eight Rajasthan districts did not want to increase herd size. The rest wanted to increase because of need for more home milk consumption and to increase income (Table 13). As to the predominant herd size, Table 13 shows that most herds (in percentage of total survey returns) have between 6 to 50 goats, with only a few keeping >50 goats.

Wanting to increase income and home consumption (from 14 to 50% of the survey returns) were strong reasons for increasing herd size in the eight districts of the state of Rajasthan (Table 13). How realistic this desire by goat farmers actually was, is documented in Tables 13, 14, 15, and 16. Apparently all herds were profitable, but the highest net incomes were derived from the value of milk when higher productivity per doe was recorded, even though expenditures were also highest in such herds. These results deserve widespread attention, because they are valid also in developed countries, as shown in the example of Greece and the United States (Tables 17 and 18) (Berger, 1998; Haenlein, 1997, 1998; Thomas and Rowe, 1998).

To improve income from goat and dairy sheep husbandry, especially for economically viable herd sizes, the research and development projects emphasized mostly nutrition, reproduction, and veterinary concerns, particularly towards reducing mortality and morbidity, which are high in many areas (Table 16) (Aboul-Naga, 1988; Acharya and Lokeshwar, 1992; Blond, 1983; Holst, 1996; IAEA, 1989; Wilson and Melaku, 1989). New technology is also of increasing interest and has led to the convening and publication of proceedings from several international symposia on machine milking of small ruminants (Eitam, 1989). This technology is very important for the production of quality milk, but lags much behind the advances in the dairy cow industry, even in developed countries, partly for financial reasons. These symposia were attended unfortunately by only a limited number of researchers from a limited number of countries mostly in the Mediterranean region, and the proceedings were to a large extent not in English, thus limiting their distribution and application.

The contribution of goat and sheep milk to human nutrition and health, especially in pediatrics, has received much too little research and refereed publica-

Table 13. Reasons for keeping goats, herd size increase, and herd size preference given in surveys of 1030 goat keeping households in eight districts of the state of Rajasthan, India.¹

	Districts of Rajasthan ²							
	1	2	3	4	5	6	7	8
I. Reasons for keeping goats								
Consumption of milk	72	31	54	43	14	22	10	44
Income from sale of kids	12	19	18	17	26	22	34	12
Consumption of milk plus sale of kids	14	44	24	35	54	53	45	40
Nursing of lambs	2	...	1	...	1	...	1	2
Manure value	...	...	...	...	2	1	6	2
Easy to keep goats	...	...	1	1	2	1	...	...
Additional income and employment	...	6	2	4	1	1	4	...
II. Reasons for increasing herd size								
Do not want to increase	59	23	42	32	45	25	24	22
Want to increase due								
to easy grazing	2	5	7	7	5	8	4	1
to increase income	16	44	35	41	27	50	41	40
for own consumption	23	25	16	19	22	14	30	37
other reasons	...	3	...	1	1	1	1	...
III. Reasons for herd size preference								
No change	59	23	42	32	45	25	24	22
<6	...	3	2	5	...	3	6	3
6 to 10	9	7	17	11	8	17	3	2
11 to 20	21	16	17	26	12	27	17	26
21 to 30	...	12	4	13	10	10	11	5
31 to 50	11	26	12	12	16	12	20	25
51 to 100	...	10	5	1	7	5	12	15
>100	...	3	1	...	2	1	7	2

¹In percentage of total survey returns from goat keeping households. Each section I., II., and III. totals 100% of household surveys (adapted from Sagar, Vidya and Kanta Ahuja, 1993).

²Districts 1 to 8 are: Sikar (56), Jaipur (188), Nagaur (133), Ajmer (75), Bhilwara (141), Udaipur (293), Sirohi (84), Barmer (60), (number of households), respectively.

tions (Table 10), while there is a large number of anecdotal and popular publications (Gurr, 1992, 1998; Haenlein, 1992, 1996a). A 1st World Congress of Dairy Products in Human Health and Nutrition was held in Madrid in 1993 (Serrano et al., 1994), which totally ignored the actual and potential contributions of goat and ewe milk to human nutrition and health. Even the subject of milk allergy received only minor coverage. Likewise, the recent 25th International Dairy Congress

treated dairy goats and dairy ewes and their products as if they do not exist (IDF Danish Nat. Comm., 1999). Fortunately, in 1992 at the 5th International Goat Conference in New Delhi (Acharya and Lokeshwar, 1992) an entire symposium focused on the role of goat meat and milk in human nutrition (Haenlein, 1992). Also in 1993 an entire issue, volume 73 (5 and 6) of the French international journal of dairy science and technology, *Le Lait*, devoted 223 pages to goat milk, although not

Table 14. Economics of goat husbandry in small herds in India.¹

	Districts of Rajasthan							
	1	2	3	4	5	6	7	8
Value of goat milk per surveyed goat household	1166	1887	1194	2050	684	395	469	711
Value of goats sold	820	2152	1454	1757	1042	217	675	286
Total income	1986	4039	2648	3807	1726	622	1144	997
Total expenditures	869	745	735	1116	328	107	296	571
No. of does	5.3	9.3	4.6	6.4	6.8	4.6	10.1	5.6
Milk production, liters/doe/yr	375	434	576	595	254	135	113	178
Expenditures per doe/yr	164	80	160	174	48	23	29	102
Net income per doe/yr ²	211	354	416	420	206	112	84	76
In US \$	5	8	10	10	5	3	2	2

¹The same districts as in Table 13 (Sagar, Vidya and Kanta Ahuja, 1993).

²All data are in Indian Rupees; US \$1.00 = 43 Rupees.

Table 15. Economics of goat husbandry in relation to other livestock.¹

	Districts of Rajasthan							
	1	2	3	4	5	6	7	8
Income from goats								
Milk	24	661	465	831	84	118	108	29
Butter-ghee	6	18	28	93	16	25	10	46
Hair	...	...	...	...	...	...	6	17
Manure	9	13	9	...	15	4	101	35
Kids, adults	781	1560	955	833	927	217	450	286
Income from cows								
Milk	50	306	57	2046	391	173	17	...
Butter-ghee	487	1309	248	348	355	174	34	93
Manure	...	17	...	...	4	...	...	14
Calves, adults	19	116	12	288	29	8	...	50
Income from sheep								
Wool	97	19	132	149	97	5	48	28
Manure	...	...	...	...	37	2	23	...
Lambs, adults	136	112	259	266	233	23	189	75
Income from camel								
Animal sales	...	24	106	...	...	...	...	...
Hire out	9	104	160	...	...	...	...	...
Others	196	21	...	141	60	20	14	165
Total	1814	4010	2431	4995	2248	769	1010	838
Goat contribution, %	45	56	60	35	46	47	68	49

¹All data in Indian Rupees (Sagar, Vidya and Kanta Ahuja, 1993).

all articles were in English (Fevrier et al., 1993; Hachelaf et al., 1993; Haenlein, 1996a; Razafindrakoto et al., 1993). The conclusions from some studies were:

- “goat’s milk has a nutritional value similar to that of cow’s milk and could be used as an alternative to cow’s milk for rehabilitating undernourished children” (Razafindrakoto et al., 1993);
- “there was a significant difference in fat absorption rate between the two groups (of 64 children) in favor

of the goat’s milk fed group; and to conclude, goat’s milk and butter appear to have a nutritional value which is at least similar to those of cow’s milk and butter as regards the clinical status of malnutrition” (Hachelaf et al., 1993);

- “minerals tended to be better absorbed from goat’s milk than from cow’s milk; goat’s milk fatty acids tended to be slightly better absorbed than the cow’s milk fatty acids, especially C14:0 and C18:2” (Fevrier et al., 1993).

Table 16. Problems (%) in sale of goat milk and general goat husbandry.¹

	Districts of Rajasthan							
	1	2	3	4	5	6	7	8
Problems in milk sales								
Insufficient milk	66	63	68	52	62	88	77	52
Low price	2	17	6	20	14	2	9	5
No buyers	12	6	9	17	7	1	6	10
Other	20	14	17	11	17	9	8	33
Not selling milk	100	84	91	69	91	99	92	100
Problems in husbandry								
Labor for grazing	75	41	53	53	59	51	36	57
Labor for milking	5	11	15	21	2	7	1	2
Water scarcity	...	3	...	...	1	1	2	3
Grazing and water scarcity	...	...	...	1	11	2	21	12
Veterinary scarcity	5	27	17	14	8	13	20	12
Grazing and veterinary scarcity	2	11	7	10	1	10	12	3
Buck scarcity	7	5	8	...	...	12	5	10
Other	6	2	...	...	2	3	1	1
No problems	...	...	...	1	16	1	2	...

¹Same districts as in Tables 13 to 16 (Sagar, Vidya and Kanta Ahuja, 1993).

Table 17. Economics of goat husbandry in Greece.¹

	Intensive farming	Extensive farming
Gross income/goat/yr, US \$	135	66
Expenses/goat/yr, US \$	111	58
Labor, %	39	52
Feed, %	43	32
Capital, %	12	13
Housing, %	4	2
Others, %	2	1
Net income/goat per year, US \$	24	8

¹Haenlein, 1998.

Concerning milk allergy, some 22 technical references from refereed journals were presented at the 5th International Goat Conference in 1992 (Haenlein, 1992) to document that goat milk is not only a good alternative to cow milk in many cases, but that in addition to protein, mineral, and vitamin differences, some much overlooked differences are in the fatty acid composition of goat and sheep milk fat, specifically in much higher contents of short and medium chain fatty acids. These have become established medical treatments in a variety of malabsorption cases, including beneficial lowering of cholesterol levels, and improvement of digestive and sleep disorders especially of children. This area has not only not been exploited in promoting the goat and dairy sheep industry, but as no butter nor ghee is made from goat or sheep milk commercially, at least outside of India, the higher contents of short and medium chain

Table 18. Economics of dairy versus nondairy sheep flocks in United States.¹

	Dairy	Nondairy
Milk sale, per ewe, \$ ²	200	0
Ram sale ³	10	2
Cull ewe sale ⁴	11	9
Lamb sale ⁵	149	233
Wool sale ⁶	4	2
Manure value ⁷	6	3
Total flock gross income, \$	114,044	74,656
Per ewe, \$	380	249
Feed expenses, \$	132	107
Management expenses	85	64
Fixed expenses	43	23
Total flock expenses, \$	78,238	58,328
Per ewe, \$	261	194
Net income/flock, \$	35,806	16,328
Per ewe, \$	119	54

¹Berger, 1998; 300 US ewe flocks.²152 L of milk/ewe per year @ \$1.32/L farm price.³6@\$500.00 for dairy; 2@\$300.00 for nondairy.⁴69@\$48.00 for dairy; 54@\$48.00 or nondairy.⁵\$1.54/kg; \$84.00 head.⁶\$5.50/kg for dairy; \$ 6.24/kg for nondairy.⁷400 MT for dairy; 200 MT for nondairy.**Table 19.** Economics of cheese making from different milks.¹

	Cow	Goat	Sheep
Farm milk cost, US \$/100 kg	28.05	48.40	143.00
Cheese making cost/100 kg milk	7.70	7.70	7.70
Total cost, US \$	33.59	56.10	150.70
Cheese yield, kg/10 kg milk	10.34	10.72	18.79
Cost/kg of cheese	3.25	5.23	8.02

¹Wendorff, 1995; making cheddar cheese; cow milk with 3.95% fat, 3.33% protein; goat milk 3.9% fat, 3.3% protein; sheep milk 6.9% fat, 5.7% protein.

fatty acids are not utilized therapeutically. Other than feeding home consumption, this fatty acid uniqueness of goat and sheep milk could be one answer to the question:

Why keep dairy goats and dairy sheep at all, when dairy cows can produce milk cheaper?

Answers to this question have been given during the 1980s in various publications that policymakers should listen to and provide much needed support in financial credit and veterinary services. This has been directed by tradition or by lobbying strength more towards the dairy cow industry (Aboul-Naga, 1988; An Min and Pan Junqian, 1989; Baker and Jones, 1985; Blond, 1983; Devendra, 1986, 1989; EAAP, 1983; Glimp and Fitzhugh, 1977; International Atomic Energy Agency (IAEA), 1989; Lu, 1987; Sumberg and Cassady, 1985; Wilson and Melaku, 1989). In the United States, leads came from the Winrock Foundation, USAID, SR-CRSP, and through USDA from the new goat experiment stations at Langston, Oklahoma, Prairie View, Texas, Fort Valley, Georgia, Tallahassee, Florida, besides San Angelo, Texas, Davis, California, and individual projects (Haenlein, 1996b). Langston University dairy goat researchers have become most productive in the United States, with annual field days reporting in 1999 for the 14th year advances in goat research (Gipson et al., 1992; Lu, 1987; Sahlu, 1999; The, 1991). FAO, ILCA, EAAP, Heifer Project International (HPI), and others sponsored important conferences in Africa, Asia, and the Mediterranean to advance the productivity of small ruminants (Becker et al., 1985; Blackburn, 1991; Devendra, 1993; El Aich et al., 1995; Iniguez and Sanchez, 1990; Lebbie and Irungu, 1994; Lindberg et al., 1997; McGowan and Gray, 1990; Morand-Fehr et al., 1995; Roeleveld and van den Broek, 1996; Saithanoo and Norton, 1991; Subandriyo and Gatenby, 1993; Wilson, 1991). Dairy sheep finally arrived in the United States in the early 1990s and a special research station at Spooner, Wisconsin, has been organized for their needs. This station has published annually detailed research information, including relative economics of dairy versus nondairy sheep operations and cheese making from different milks (Tables 18 and 19) (Berger, 1998;

Thomas et al., 1995; Thomas and Porter, 1999a, 1999b; Thomas and Rowe, 1998; Thomas and Wagner, 1995; Wendorff, 1995).

Research—Future Perspectives

How to reach farmers with small ruminants for improvement of their productivity and their livelihood has been the central topic of many of the cited conferences and publications. The presence or absence of extension service workers in some countries is a major concern and has led to the establishment of networks for the dissemination of information worldwide, especially in the Mediterranean area (Lebbie and Irungu, 1994; Lindberg et al., 1997; Morand-Fehr et al., 1995). Even with a presence of extension workers, it is often the topography of the country that presents enormous obstacles to information transfer, although the perspectives in the future are bright thanks to the rapid progress of wireless communication systems at affordable prices. Even in a developed country like Greece, e.g., whose people depend very much on the products from small ruminant husbandry, access to farmers is often very difficult, as three fourths of this country is rugged mountains. This condition is similar in many developing countries, and the problems are increased by transhumance shepherding and nomadic grazing management of many sheep and goat herds (Haenlein, 1998).

On the other extreme, commercial dairy goat and dairy sheep farmers with intensive dry lot and stable systems have the benefit of the most advanced information and technology (Gruner and Chabert, 2000; Morand-Fehr and Boyazoglu, 1999; Rubino and Haenlein, 1996). This system is typically found in France and Taiwan, and now as a new beginning also in United States (Boylan, 1989b; Haenlein and Ace, 1984; Thomas et al., 1995; Thomas and Porter, 1999a, 1999b; Thomas and Rowe, 1998; Thomas and Wagner, 1995). While farmers in the mountains and deserts must not be encouraged to leave for the city, as this creates many new sociological problems, a certain amount of government or private industry support is very much necessary to keep mountain and desert farmers in their traditional habitats (Coop, 1982; Haenlein, 1998). It can be done as practiced for several years successfully in Austria and Switzerland. Nevertheless, it must be recognized that even in the future and under the best circumstances, farmers with small ruminants are found in four distinctly different locations (Wilson and Lebbie, 1996) with their inherent consequences:

- rural areas with good road access, where a market-oriented approach is gradually emerging, and where farmers are willing to pay for services;
 - rural areas without road access, where production is still basically subsistence oriented, and where a gradual and sympathetic approach to payment for services will be needed;
 - remote mountain areas, where farmers with very few resources will need considerable time to accept that payment for services must be made.
- Some conferences have tried to project needs of small ruminant husbandry and research for the future (Devendra and Gardiner, 1995a, 1995b; Gardiner and Devendra, 1995; Haenlein, 1980c, 1986, 1996b; Haenlein and Fahmy, 1999; Peacock, 1996; Raghavan et al., 1990). Most are driven by projections of population increases and how to feed these people. Differences in location condition should dominate differential perspectives of needs and potential accomplishments. Overall, the prospects for small ruminant farming are bright (Devendra, 1999a, 1999b; Zhu et al., 1999) (Tables 10 to 17), because there continues to be a greater demand than there is supply of dairy products from small ruminants, and profitable management has been documented.
- Two major research needs transcend all improvement and development topics (Devendra and Gardiner, 1995a, 1995b; Gardiner and Devendra, 1995; Haenlein, 1992, 1996a, 1997, 1998, 1999; Morand-Fehr and Boyazoglu, 1999; Wilson and Lebbie, 1996):
- identify better and promote the marketing of the unique values of dairy products from goat and sheep milk, so to better justify their existence and higher prices for their products;
 - improve conditions of family livelihood and better net income levels of small ruminant farmers to achieve keeping the farmer and his family content in this enterprise and reduce off-farm migration.
- Much of this has been spelled out in detail in thought-provoking proceedings of Global Research Agenda workshops for each continent (Devendra, 1999a, 1999b, 2000; Devendra and Gardiner 1995a, 1995b; Gardiner and Devendra, 1995; Haenlein and Fahmy, 1999; Morand-Fehr and Boyazoglu, 1999). Also, the concept of information dissemination principally via conferences is continuing (Haenlein, 1999), as the new century had already scheduled the 7th International Goat Conference in France (Gruner and Chabert, 2000), a Small Ruminant Strategy Seminar at Cyprus, symposia in Algiers and in Egypt, and more to come certainly. For the United States, it has been and will be important to be more involved, which should include annual, na-
- urban and periurban areas with semi-intensive and intensive commercial enterprises, which can pay for services;

tional statistics on dairy goat and dairy sheep numbers, tonnage of milk and cheese produced, updating and expanding NRC Nutrient Requirement publications for dairy goats as well as for dairy sheep, and research especially concerning quality standards of their dairy products.

CONCLUSION

Perspectives for future small ruminant dairy research can be drawn from the trends of the last 20 yr (Tables 4 and 5). Some countries need significantly better supplies of protein and calcium from dairy product sources (Tables 6 and 8), and some countries need to improve apparent productivity per animal (Table 7). As profitable economics of small ruminant dairy management has been demonstrated, the economic significance of small ruminants and research into their uniqueness should increasingly be a priority in many countries.

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