

REVIEW ARTICLE

Composition and characteristics of camel milk

BY ZAKARIA FARAH

Laboratory of Dairy Science, Swiss Federal Institute of Technology (ETH)
ETH-Zentrum, CH-8092 Zürich, Switzerland

(Received 22 February 1993 and accepted for publication 28 February 1993)

CONTENTS

	PAGE		PAGE
Introduction	603	Phospholipids	613
Present distribution and milk production	604	Physical state and properties of fat globules	614
Main components	605	Lactose	616
Gross composition	605	Minerals and vitamins	616
Overall protein composition	606	Enzymic coagulation	617
Casein fractions	607	Effects of heat on milk	620
Size distribution of casein	609	Antibacterial activity	623
Whey protein fractions	611	Conclusions	623
Lipids	612	References	624
Fatty acid composition	612		

INTRODUCTION

Camels belong to the family *Camelidae* and thereby to the suborder Tylopoda. The tylopoda themselves belong to the order Artiodactyla or cloven-footed animals. The family of *Camelidae* contains the genera *Camelus* (old world camel) and *Lama* (new world camel). The *Camelidae* originated in North America where the earliest fossil remains of *Camelidae* have been found. The genus *Camelus* migrated from North America in the late Tertiary across the then existing land bridge to Asia and Africa. The llamas on the other hand reached South America in the ice age across the Central American land bridge. Included in the genus *Camelus* are the one-humped dromedary (*Camelus dromedarius*) and the two-humped bactrian (*Camelus bactrianus*). The term dromedary is derived from the Greek 'dromados' (run) and in the strict sense is used for riding camels. The name 'Bactrian' for the two-humped camel refers to the area 'Bactria' in North Afghanistan where this type of camel is thought to have originated. The dromedary is slim, long-legged, short-haired and has its habitat in warm arid and semi-arid areas. The bactrian is stockier, short-legged and has a thicker and longer coat than the dromedary. It mainly occurs in cold and mountainous areas (Simpson, 1945; Zeuner, 1963).

This review is concerned entirely with the one-humped camel; the term 'camel' should therefore be taken to refer to *Camelus dromedarius* unless specifically stated otherwise.

The majority of the studies conducted on camels concentrate on anatomical features, traditional management and physiological adaptation to desert conditions (Cauvet, 1925; Schmidt-Nielsen, 1964; Bulliet, 1975; Gauthier-Pilters & Dagg, 1981;

Table 1. *Estimated camel populations of Africa and the rest of the world in 1978†*

Country	Camel population, thousands	Country	Camel population, thousands
Africa		Sudan	2904
Algeria	147	Tunisia	205
Chad	26	Upper Volta	5
Djibouti	405	West Sahara	86
Egypt	95		
Ethiopia	960		
Kenya	574	Other regions	
Libya	75	Afghanistan	290
Mali	198	China	1040
Mauretania	718	India	1174
Morocco	20	Iraq	232
Niger	350	Mongolia	615
Nigeria	18	Pakistan	819
Senegal	6	Saudi Arabia	108
Somalia	5400	USSR	230

† From FAO (1979).

Table 2. *Average milk yields of camels reported from various sources*

Country	Daily yield, kg	Lactation length, months	Calculated lactation yield of 305 d, kg	Reference
Egypt	3.5-4.5	9	1068-1373	El-Bahay (1962)
Ethiopia	5-13	12-18	1525-3965	Knoess (1977)
India	7-18	15	2105-5551	Rao (1974)
Kenya	2-12	11-16	610-3660	Field (1979)
Pakistan	8-10	12	2440-3050	Knoess (1979)
Somalia	3-9	9-18	915-2745	Hartley (1979)
Sudan	5-10	10-12	1525-3050	El-Amin (1979)
Tunisia	4	12	1220	Bürgemeister (1974)

Wilson, 1984; Yagil, 1985). Information about camel milk is mostly limited to some data on gross composition. Studies on individual components and their physico-chemical characterization have received very limited attention. The present review attempts to place the scarce available information on camel milk components into a coherent framework. Emphasis is given to comparison with bovine milk. This is natural in as much as bovine milk has been the subject of intensive research over a long period and, although many areas of uncertainty still exist, the general physicochemical properties of all main components of bovine milk are well established.

PRESENT DISTRIBUTION AND MILK PRODUCTION

According to FAO (1979) statistics (Table 1) there are ~ 17 million camels in the world, of which 12 million are found in Africa and 4.9 million in Asia. Of this estimated world population, 15 million are believed to be one-humped camels and 1.9 two-humped. Of the camel population, 60% is concentrated in the four North East African countries Somalia, Sudan, Kenya and Ethiopia; Somalia, with over 5 million, has the largest herd in the world.

Some of the existing data on milk yields of the dromedary are summarized in Table 2. For better comparison, milk yields are calculated for a lactation period of 305 d. Reported milk yields vary from 3.5 kg for animals under desert conditions up to 18 kg for animals in irrigated land.

Table 3. *Proximate composition of camel milk*

(Values are g/kg)

Dry matter	Fat	Lactose	Protein	Ash	Reference
98	32	42	27	6	Desai <i>et al.</i> (1982)
144	55	34	45	9	Knoess (1977)
119	36	44	30	8	Sawaya <i>et al.</i> (1984)
130	33	56	33	8	Gnan & Sheriha (1986)
134	32	48	40	7	Abdel-Rahim (1987)
113	33	47	27	9	Abu-Lehia (1987)
110	35	39	25	8	Hassan <i>et al.</i> (1987)
142	38	55	40	8	Abu-Lehia <i>et al.</i> (1989)
122	32	52	31	8	Farah & Rüegg (1989)
119	32	45	34	8	Mehaia & Al-Kahnal (1989)
134	36	55	33	8	Bayoumi (1990)

It is difficult to estimate the daily milk yield of a camel under pastoral conditions. On the one hand, throughout lactation the calves are still sucking and therefore the actual volumes of milk secreted are higher than the figures presented in Table 2. On the other hand, milking frequency varies among the different pastoral groups. Camels may be milked once a day, among the Murah of Arabia (Cole, 1975), from two to four times among the Somali (Bremaud, 1969; Hartley, 1979) and the Rendille of Kenya (Spencer, 1973) and as many as six or seven times among the Afar of Ethiopia (Knoess, 1977). The Afars may also leave their animals unmilked for a whole day, which may account for sporadic very high estimates. Milk yields will also vary with species, breed, feeding and management conditions, and stage of lactation. The dromedary, like most other species, gives most milk near the beginning of the lactation period. In a study of the camels of Northern Kenya, Field (1979) estimated their daily yield at 21 l in the second week of lactation falling to 4.8–2.2 l by the sixteenth week of lactation. The average length of lactation in the camel is 12 months, but it may vary from 9 to 18 months, depending on management and environmental conditions.

The milk yield estimates presented in Table 2 indicate that the camel is potentially a better milker than many African Zebu cows under the same environmental conditions. The daily milk yield of Zebu cows varies between 0.5 and 1.5 kg (Kiwuwa, 1973). Spencer (1973) estimated that in Kenya one Rendille camel produced as much milk as four cows in the same region.

MAIN COMPONENTS

Gross composition

Camel milk is generally opaque-white. It has a sweet and sharp taste, but sometimes can also be salty. The changes in taste are caused by the type of fodder and availability of drinking water. The pH of camel milk ranges from 6.5 to 6.7 with an average value of 6.56, and the density from 1.025 to 1.032 with an average of 1.029. Both values are lower than those of cows' milk (El-Bahay, 1962; Rao *et al.* 1970; Shalash, 1979; Sawaya *et al.* 1984; Farah & Bachmann, 1987).

Some recent data on the composition of camel milk are presented in Table 3. The differences among the various sets of data undoubtedly reflect differences in breed and state of lactation of the animals sampled, in sampling procedures and perhaps in analytical procedures as well.

One of the important factors that affects camel milk composition is the water. Yagil & Etzion (1980) examined the effects of restricting drinking water on camel

Table 4. Nitrogen distribution in camel milk

Protein fractions, g/100 g		As % of total N			Reference
Casein	Whey protein	Casein N	Whey protein N	Non-protein N	
2.2	0.8	74	21	4.6	Urbisnov <i>et al.</i> (1981)
2.1	0.7	76	17	6.7	Farah & Rüegg (1989)
1.9	0.9	72	22	6.2	Abu-Lehia (1987)
2.3	1.0	71	23	5.8	Bayoumi (1990)
(2.2-3.8)†	(0.5-0.9)	(72-78)	(17-22)	(4.7-5.5)	

† Values in parentheses are ranges for cows' milk.

milk. While the diet remained unchanged throughout the year, great changes in water content of milk were found. The camels were allowed drinking water *ad lib.* only during the winter. From spring until the end of summer, the mothers and the calves were allowed to drink only once a week for 1 h. With water freely available the water content of the milk was 86%, but when water was restricted the water content of milk rose to 91%. These changes reflect the reported range and this makes it important when the milk was sampled by the various investigators. This study shows that the lactating camel loses water to the milk in times of drought. This could be a natural adaptation in order to provide necessary fluid to the dehydrated calf.

The colostrum of camels is white and slightly diluted as compared with the colostrum of the cow (Rao *et al.* 1970; Yagil & Etzion, 1980). Only fragmentary data are available on colostrum composition in camel milk. The most complete data are those reported by Sestucheva (1958) and Abu-Lehia *et al.* (1989) for Russian and Saudi camels. Sestucheva studied ten Kazakhstan camels. The first colostrum obtained after 3 h post partum contained on average 30.4% total solids, 0.20% fat, 19.4% protein, 7.2% lactose and 3.8% minerals. During the first 2 d of lactation the solids content fell to 18.4%, mainly owing to the decline of total proteins to 3.6% and minerals to 0.1%. The fat content increased to 5.8% whilst the lactose level remained practically unchanged. The composition then remained fairly constant until the tenth day when the experiment ended.

Abu-Lehia *et al.* (1989) examined the colostrum of ten Saudi camels (Majaheem breed) during their first season of lactation up to 10 d post partum. At parturition, the contents of total solids, fat, protein, lactose and minerals were 20.5, 0.20, 13.0, 2.7 and 1.0% respectively. After 3 d total solids decreased to 13.6%, protein to 4.7% and minerals to 0.8%. However, the fat content rose to 1.5% and lactose to 4.4%.

Overall protein composition

The N distribution of camel milk from four different regions is presented in Table 4. All authors used the method of Rowland (1938) modified by Aschaffenburg & Drewry (1959) for determining the N fractions.

The average casein and whey protein content in camel milk varies between 2.3 and 1.9% and 0.7 and 1.0% respectively. The values of casein N, whey protein N and non-protein N (NPN), expressed as a percentage of the total milk protein N, lay within the ranges 71-76%, 17-23% and 5.8-4.6% respectively. The results in Table 4 indicate that the protein and N fractions in camel milk are generally similar to those in cows' milk. However, camel milk seems to contain somewhat higher amounts of NPN fractions than cows' milk.

Recent data on amino acid composition of camel milk protein are presented in Table 5. Amino acid content appears generally similar to that of cows' milk protein.

Table 5. Amino acid composition of camel and cows' milk

(Values are g/100 g total protein)

Amino acid	Camel (Sawaya <i>et al.</i> 1984)	Camel (Mehaia & Al-Kahnal, 1989)	Cow (Renner, 1991)
Alanine	2.8	2.7	3.5
Arginine	3.9	3.8	3.7
Aspartic acid	7.6	6.4	7.9
Cysteine	—	—	—
Cystine	1.0	0.6	0.7
Glutamic acid	23.9	19.5	21.8
Glycine	1.7	1.3	2.1
Histidine	2.5	2.7	2.8
Isoleucine	5.4	5.0	6.4
Leucine	10.4	9.5	10.4
Lysine	7.0	7.1	8.3
Methionine	2.5	3.6	2.7
Phenylalanine	4.6	5.6	5.2
Proline	11.1	11.1	10.0
Serine	5.8	4.2	5.6
Threonine	5.2	4.3	5.1
Tryptophan	1.2	—	1.4
Tyrosine	4.5	4.0	5.3
Valine	6.1	6.9	6.8

Table 6. Caseins of camel milk

Casein	Molecular mass, Da	Reference
α_{s1}	35000	Farah & Farah-Riesen (1985)
α_{s1}	31000	Larsson-Raznikiewicz & Mohamed (1986)
α_{s2}	25000	Larsson-Raznikiewicz & Mohamed (1986)
β	35000	Farah & Farah-Riesen (1985)
β	27000	Larsson-Raznikiewicz & Mohamed (1986)

Casein fractions

According to early nomenclature of cows' milk proteins (Whitney *et al.* 1976), caseins were defined as those phosphoproteins that precipitate from raw skim milk upon acidification to pH 4.6 at 20 °C. Individual caseins were isolated and defined according to their electrophoretic mobility in alkaline polyacrylamide or starch gels. The latest report on milk protein nomenclature (Eigel *et al.* 1984) recommends abandoning the use of electrophoresis as a basis for casein classification and identifying caseins according to the homology of their primary structure.

The camel milk caseins reported here and presented in Table 6 are obtained by acid precipitation at pH 4.6 and identified by electrophoresis. At present the primary structure of the individual caseins is not known. Thus the designation α and β given to camel casein fractions is still uncertain and remains to be confirmed.

Two casein fractions homologous to bovine α - and β -casein have been isolated from camel casein (Farah & Farah-Riesen, 1985). The casein fraction was obtained by the usual acid precipitation following the same pattern as that for cows' milk casein. Fig. 1 shows the electrophoretic pattern of camel milk, acid-precipitated camel casein, fraction B, which is isolated according to the β -casein preparation method of Aschaffenburg (1963), and fraction A, obtained as α -casein by the urea method of Hipp *et al.* (1952). Fractions A and B can be considered as possibly homologous to bovine α - and β -casein. Fraction B (β -casein) is clearly separated and

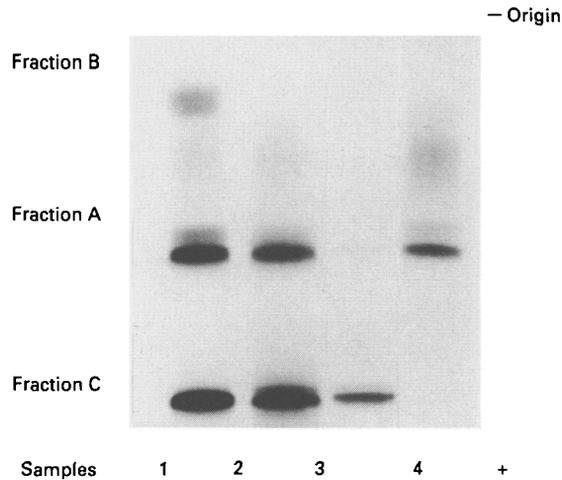


Fig. 1. PAGE patterns of camel milk and camel milk casein fractions: 1, fraction A; 2, fraction B; 3, whole camel casein; 4, camel milk (Farah & Farah-Riesen, 1985).

consists of a single strong band. Fraction A (α -casein) shows one strong band and some diffuse slow moving bands. In general α -casein occurs in bovine milk as a mixture of many subfractions such as α_{s1} and α_{s2} . The fractionation method applied suggests the strong band to be homologous to bovine α_{s1} -casein and the diffuse band moving behind to be α_{s2} -casein. No protein bands homologous to bovine κ -casein could be clearly detected in the electrophoretic pattern. The molecular masses of the camel casein fractions were estimated by means of SDS-PAGE to be 32 kDa for fraction B (β -casein) and 35 kDa for fraction A (α -casein). These values are higher than those of bovine caseins, usually reported as 24 kDa for β -casein, 22 kDa for α_{s1} -casein and 25 kDa for α_{s2} -casein (Eigel *et al.* 1984).

Larsson-Raźnikiewicz & Mohamed (1986) isolated four casein fractions by ion-exchange chromatography and identified them by PAGE. Amino acid and phosphorus analysis revealed that proteins analogous to the α_{s1} -, α_{s2} -, β - and κ -caseins of bovine milk occur in camel milk. For camel milk, α_{s1} - and β -casein predominated: α_{s2} -casein gave diffuse bands. No protein band corresponding to κ -casein could be detected. This fraction could be isolated only by ion-exchange chromatography and was identified as homologous to bovine κ -casein on the basis of its amino acid composition. Furthermore the α_{s1} - and β -casein of camel milk were phosphorylated to about the same extent, and α_{s2} -casein was more heavily phosphorylated than the corresponding bovine casein. In Table 7 the amino acid compositions of the different casein fractions isolated by ion-exchange chromatography are given. It shows that there are close similarities in amino acid composition between the camel and bovine casein fractions. The molecular masses estimated from SDS-PAGE were 27, 31 and 25 kDa for β -, α_{s1} - and α_{s2} -casein respectively. These values differ from those obtained by Farah & Farah-Riesen (1985) for camel α - and β -caseins, with β -casein showing the larger deviation.

Pant & Chandra (1980) and Hassan *et al.* (1987) also reported the occurrence of proteins homologous to cows' milk α - and β -casein in camel milk, but without sufficient information on the methods used.

Table 7. Amino acid composition of camel and cows' milk casein†

(Values are g/100 g total casein)

Amino acid	β -Casein		κ -Casein		α_{s1} -Casein		α_{s2} -Casein	
	Camel	Cow	Camel	Cow	Camel	Cow	Camel	Cow
Alanine	2.9	2.4	4.8	8.3	3.0	4.5	2.9	3.9
Arginine	1.9	1.9	2.7	3.0	4.9	3.0	1.8	2.9
Aspartic acid	3.8	4.3	6.2	7.1	9.1	7.5	6.5	8.7
Cysteine	0.0	0.0	0.6	1.2	0.0	0.0	1.0	1.0
Glutamic acid	19.5	18.7	17.7	16.0	20.9	19.6	21.8	19.3
Glycine	1.2	2.4	2.2	1.2	2.3	4.5	1.9	1.0
Histidine	1.8	2.4	1.9	1.8	2.3	2.5	2.7	1.4
Isoleucine	5.7	4.8	6.9	7.1	6.2	5.5	5.3	5.3
Leucine	10.8	10.5	7.2	4.7	8.0	8.5	5.1	6.3
Lysine	5.9	5.3	5.6	5.3	7.3	8.0	10.6	11.6
Methionine	2.9	2.9	1.5	1.2	1.7	2.5	1.6	1.9
Phenylalanine	3.8	4.3	3.6	2.4	2.7	4.0	5.1	2.9
Proline	18.3	16.7	14.4	11.8	8.4	8.5	5.1	4.8
Serine	6.1	7.7	6.3	7.7	8.0	8.0	6.7	8.2
Threonine	5.0	4.3	7.1	8.9	4.9	2.5	8.0	7.2
Tyrosine	2.5	1.9	3.6	5.3	4.6	5.0	5.7	5.8
Tryptophan	0.0	0.5	0.7	0.6	1.0	1.0	2.2	1.0
Valine	8.0	9.1	7.1	6.5	4.8	5.5	6.1	6.8

† From Larsson-Raźnikiewicz & Mohamed (1986).

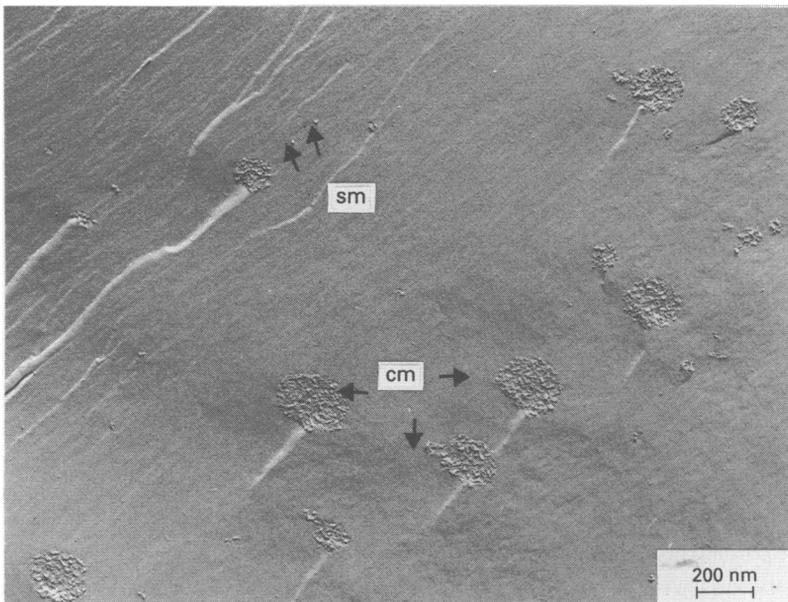


Fig. 2. Freeze-fractured casein micelles in camel milk: cm, casein micelles; sm, submicelles (Farah & Rűegg, 1989).

Size distribution of casein

The casein micelle is the backbone of the colloidal milk system, and determines milk stability. There are no reports that give a detailed picture of the micellar state of casein in milk other than cows' milk. The state of the casein micelle structure in camel milk has seldom been investigated. At present, there are only the following

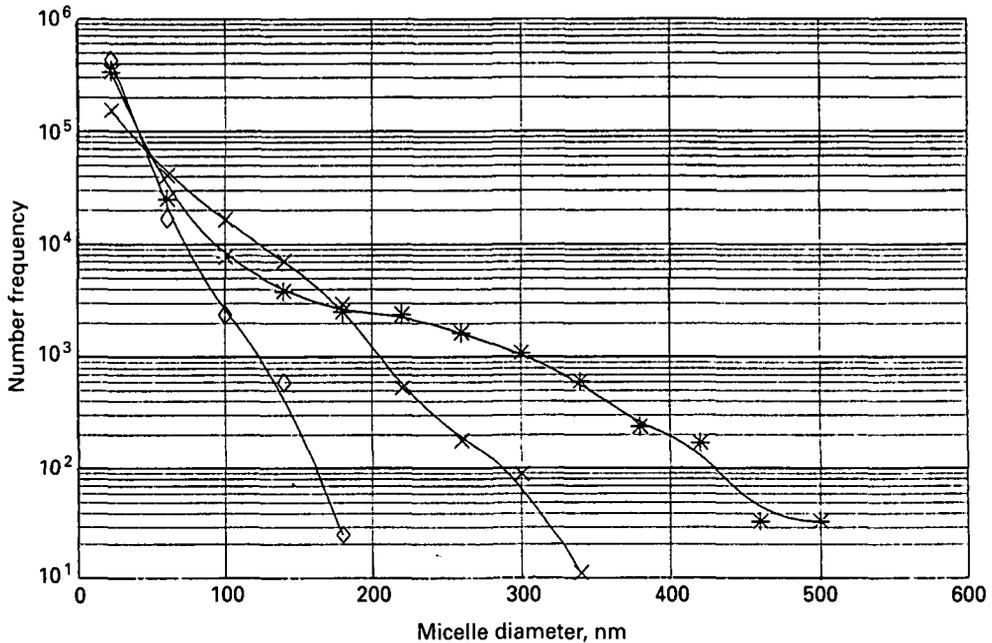


Fig. 3. Number of particles observed in freeze-fractured *, camel; ×, cows' and ◇, human milk. The ordinate is logarithmic and gives the number of particles per mm² fractured areas and per nm classes widths (Farah & Rüeegg, 1989).

three reports published on the subject. Gouda *et al.* (1984) examined the casein micelles of an unspecified number of Egyptian camel milk samples. The milk was solidified with agar and examined in thin sections by electron microscopy. The casein micelles ranged in size from 25 to > 400 nm. The technique did not allow clear identification of smaller micelles. Ali & Robinson (1985) analysed the size distribution of casein micelles in six samples of camel milk using transmission electron microscopy. Milk was collected from individual Bedouin camels reared by nomads from the Sudan. The total number of particles counted was 2448. They found that the majority of the casein micelles had comparatively small diameters of 28–240 nm. The number average diameter of casein micelles was 160 nm. However, this value overestimates the true mean because particles with diameters < 14 nm could not be measured. Farah & Rüeegg (1989) studied the casein micellar structure of milk from ten individual camels of Northern Kenya. The size distribution of casein micelles in camel milk was determined by electron microscopy. The milk samples were cryofixed and freeze-fractured. The total number of particles counted was 6618.

Fig. 2 shows a typical electron micrograph of casein particles in a freeze-fracture sample of camel milk. The mean diameter of the submicelles was on average 15 nm. The average number of particles observed on such freeze-fractured surfaces is shown graphically in Fig. 3. The distribution is significantly broader than that of cows' and human milk (Rüeegg & Blanc, 1982) and shows a greater number of large particles.

The particles in the lowest size class with diameters < 40 nm comprise ~ 80% of the observed total number of particles, but represent only 4–8% of the mass or volume of the casein in camel milk. It is therefore meaningful to consider the weight or volume frequency distribution. Fig. 4 shows the volume frequency of the pooled data for the camel milk samples compared with the distributions found in bovine and

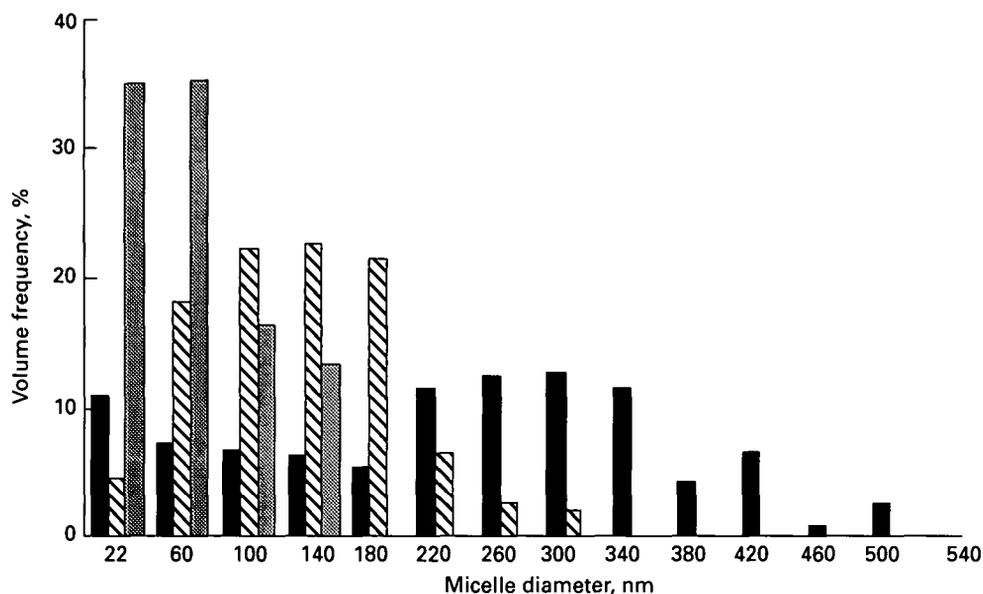


Fig. 4. Size distribution of casein micelles in camel milk (■) compared with cows' milk (▨) and human milk (□) (Farah & Rüeegg, 1989).

Table 8. *Whey proteins of camel milk*

Whey protein	Molecular mass, Da	Reference
Immunoglobulin	—	Conti <i>et al.</i> (1985)
Serum albumin	—	Conti <i>et al.</i> (1985)
Serum albumin	66000	Farah (1986)
Serum albumin	—	Beg <i>et al.</i> (1987)
α -Lactalbumin A	14000	Conti <i>et al.</i> (1985)
α -Lactalbumin B	14000	Conti <i>et al.</i> (1985)
α -Lactalbumin	14000	Farah (1986)
α -Lactalbumin†	14600	Beg <i>et al.</i> (1985)
Novel camel whey†	14000	Beg <i>et al.</i> (1986)
Novel camel whey†	15000	Beg <i>et al.</i> (1987)

† Primary structure determined.

mature human milk (Rüeegg & Blanc, 1982). The volume distribution curve of casein micelles in camel milk is broad and shows a maximum between 260 and 300 nm (cows' milk 100–140 nm).

From the few available data on camel casein micelles presented here it can be concluded that camel milk casein differs from cows' milk casein in terms of micellar size distribution. Some possible consequences of this difference in relation to rennet coagulation properties of camel milk will be discussed later.

Whey protein fractions

The term 'whey protein' should be used only in a general sense to describe milk proteins soluble at pH 4.6 and 20 °C (Eigel *et al.* 1984). Classification of individual whey proteins should be based on the primary sequence of the amino acids in their polypeptide chains, although gel electrophoresis can still be used to characterize and identify the individual whey proteins.

The camel whey proteins reported below and presented in Table 8 were obtained from raw skim milk. The caseins were removed either by acidification to 4.6 or by

high speed centrifugation. Individual whey proteins have been identified according to their chromatographic and electrophoretic mobilities. Some whey proteins were classified on the basis of the primary sequence of their amino acid chains.

Conti *et al.* (1985) separated camel whey proteins by gel chromatography on Sephadex G100 and identified some components using electrophoretic methods. The study revealed the presence of immunoglobulins and serum albumin in camel whey proteins. In the study two different α -lactalbumins were isolated and characterized. These two proteins, α -lactalbumin A and B, had similar molecular masses (~ 14 kDa), immunological properties and electrophoretic mobility, but had different isoelectric points, amino acid composition and N-terminal sequence.

Farah (1986) examined whey proteins of camel milk by SDS-PAGE. The study revealed four clearly separated whey proteins. By comparing with standard marker proteins, two protein bands could be shown to be identical to standard bovine serum albumin (molecular mass 66 kDa) and α -lactalbumin (molecular mass 14 kDa). The other whey proteins of molecular masses 23 and 43 kDa could not be identified.

Beg *et al.* (1985) separated camel whey proteins by gel chromatography on Sephadex G25 and purified them by reversed-phase HPLC. Amino acid and primary structure analysis revealed the presence of whey proteins homologous to bovine α -lactalbumin. The isolated camel α -lactalbumin has a molecular mass of 14.6 kDa and was found to contain 123 amino acid residues, like bovine α -lactalbumin. Mobility on SDS-PAGE was also identical for the two proteins. In other studies Beg *et al.* (1984, 1986, 1987) isolated and characterized two camel whey proteins that have no homology with known bovine milk whey proteins. One of the novel camel whey proteins with molecular mass 14 kDa is rich in cysteine/half-cysteine. Its 117 amino acid residues have 16 half-cysteine residues. Such residues usually occur in disulphide links in milk and other extracellular proteins. Thus, the new camel whey protein is likely to have a rigid, highly cross-linked polypeptide chain. This new protein exhibited some structural similarities to bovine β A2-casein in the N-terminal region. The similarity affected those residues known to be phosphorylated in β -casein. However, β -casein lacks cysteine residues. The other new camel whey protein found in these studies has a molecular mass of 15 kDa. It consists of 112 amino acid residues and does not contain cysteine. No obvious structural similarities were noted between the novel milk proteins and other milk proteins characterized.

Lipids

Lipids in milk fat serve nutritionally as an energy source, act as a solvent for the fat-soluble vitamins and supply essential fatty acids. In milks of all species studied to date, triacylglycerols are by far the major lipid class of milk fat, accounting for 97–98% of the total lipids in most species. The triacylglycerols, which contain a great variety of fatty acids, are accompanied by small amounts of diacylglycerols and monoacylglycerols, cholesterols, free fatty acids and phospholipids.

The fat content in camel milk varies between 2.7 and 3.6%. Most of the data available on camel milk fat are on the fatty acid composition and to a lesser extent on phospholipids and some properties of fat globules.

Fatty acid composition

According to the limited information available, the first data on fatty acid composition in camel milk fat were published by Dhingra (1934), who examined the milk fat of Indian camels using older techniques of fractional distillation. This work was followed by the studies of Glass *et al.* (1967), who reported on the fatty acid

Table 9. *Fatty acid composition of camel and cows' milk fat*

(Values are g/100 g total fatty acids)

Fatty acid	Camel milk fat			Cows' milk fat
	Farah <i>et al.</i> (1989)	Abu-Lehia (1989)	Gnan & Sheriha (1986)	Abu-Lehia (1989)
4:0	0.66	—	1.0	3.5
6:0	0.37	—	—	2.1
8:0	0.23	0.1	0.5	1.4
10:0	0.90	0.12	0.1	2.1
10:1 n -7	0.19	—	—	—
12:0	0.79	0.77	0.5	3.1
12:1 n -7	—	—	0.1	—
13:0	—	—	0.1	—
14:0	12.5	10.1	10.0	10.4
14:1 n -5	1.1	1.86	1.5	1.70
15:0	1.3	1.62	0.5	2.44
15:1 n -5	0.23	—	—	—
16:0	31.5	26.6	31.5	26.60
16:1 n -7	9.4	10.40	9.0	1.70
17:0	0.92	1.21	0.5	1.62
17:1 n -8	0.60	—	0.5	—
18:0	12.5	12.2	14.0	7.86
18:1 n -9	19.1	26.3	25.0	29.0
18:2 n -6	3.4	2.94	3.0	3.20
18:3 n -3	1.4	1.37	—	1.10
20:0	1.03	0.57	0.5	0.11
22:0	—	0.08	—	0.23
2:1 n -7	—	0.57	—	—

composition of milk fat from 57 species, including camels. Further data on the subject are provided by the studies of Sawaya *et al.* (1984), Gnan & Sheriha (1986), Hagrass *et al.* (1987), Abu-Lehia (1989) and Farah *et al.* (1989). Some representative data on the composition of the main fatty acids in camel milk fat are listed in Table 9. All the data were obtained by gas-liquid chromatography. The list is weighted in favour of the more recent studies and, as far as can be judged, the camels were fed all year round exclusively by grazing with no supplementary feed. Fatty acids of milk from cows living under the same conditions are also given for comparison.

Fatty acid composition is influenced to some degree by environmental and physiological factors such as diet, stage of lactation and genetic differences. Within these limitations, the general pattern of the camel milk fatty acids indicates that short-chain fatty acids, C₄-C₁₂, are present in very small amounts in camel milk fat compared with cows' milk fat, but that the concentrations of C14:0, C16:0 and C18:0 are relatively high.

Phospholipids

Phospholipids are a small but important fraction of the lipids of milk and are found mainly in the milk fat globule membrane. At present the work of Morrison (1968*a, b*) provides the only information available on phospholipids in camel milk. Phospholipids were isolated from the milks of cow, sheep, Indian buffalo, ass, pig, human and camel by quantitative two dimensional thin layer chromatography. The distribution of phospholipids was found to be constant in the milks of all the species studied. However, the study showed that phospholipid fatty acids of camel milk are not entirely characteristic of the ruminant herbivores.

The ruminant herbivores have branched-chain fatty acids in all their phospho-

lipids; they have only a small proportion of fatty acids with more than two double bonds. Their sphingomyelin contains a high proportion of tricosanoic acid (23:0) but little nervonic acid (24:1n-9).

Camel milk phospholipid fatty acids have high amounts of linoleic acid (18:3n-3) and long-chain polyunsaturated acids. Its sphingomyelin contains a higher proportion of nervonic acid and lower tricosanoic acid than that of the ruminant herbivores.

Camel milk phosphatidylethanolamine is also unusual in that it contains 15% plasmalogen whereas the largest amount reported in other phospholipids is 4% plasmalogen in bovine milk phosphatidylcholine (Morrison *et al.* 1965).

Physical state and properties of fat globules

The bulk of the fat in milk exists in the form of small spherical globules of varying sizes. The surface of these fat globules is coated with a thin layer known as the fat globule membrane, which acts as the emulsifying agent for the fat suspended in milk. Until recently the fat globule membrane of camel milk had not received much attention.

Gouda *et al.* (1984) reported an electron microscopy study on the size distribution of fat globules of camel milk. Milk from camels was solidified with agar and examined in thin sections under the electron microscope. Fat globules ranged in diameter from 1 to 5 μm with nearly 50% in the 2-3 μm range.

Knoess *et al.* (1986) analysed camel milk from five different animals for the size of fat globules and found an average globule size between 2.31 and 3.93 μm . He found that the fat globule membrane in camel milk was far thicker than in other types of milk, the term 'thickness' being used in relation to the diameter of the fat globule.

In a study on some physical properties of camel milk, Wahba *et al.* (1988) found that the size of the fat globules in camel milk varied between 2.60 and 3.25 μm with an average of 2.9 μm .

The size distribution of camel milk fat globules was determined by light microscopy (Farah & Rüegg, 1991). A total of 1800 particles was counted. Fig. 5 shows the frequency distribution of fat globules in camel milk compared with the distribution found in cows' milk (Precht *et al.* 1987). The results show similar globule size distributions in bovine and camel milks. From the light microscopy data a number average diameter of 2.61 μm , a volume to surface mean diameter of 4.40 μm , a weight average diameter of 5.11 μm and a distribution width of 40.1% could be calculated.

All the studies presented here indicate that fat globule size distribution of camel milk is similar to that in cows' milk.

The creaming properties of fat globules in camel milk have been recently studied by Farah & Rüegg (1991). The natural creaming of raw and heated camel milk was examined in comparison with cows' milk. The milk samples were heated for 30 min at 55, 60, 62, 68, 70 and 77 °C. The milk samples were left to cream at 4 °C and the cream layer was measured after 5 and 24 h. Compared with cows' milk, camel milk showed a very slow creaming rate at all temperatures. Creaming layers varied from 0.5 to 2 ml at 4 °C.

It is well established that the main factor responsible for rapid formation of the cream layer on cows' milk is a protein adsorbed on cold fat globules, which has the characteristics of a euglobulin. This protein, known as fat agglutinin, promotes clustering of globules (Mulder & Walstra, 1974). To test whether the low creaming capacity of camel milk could be due to a deficiency in agglutinin, creaming capacity

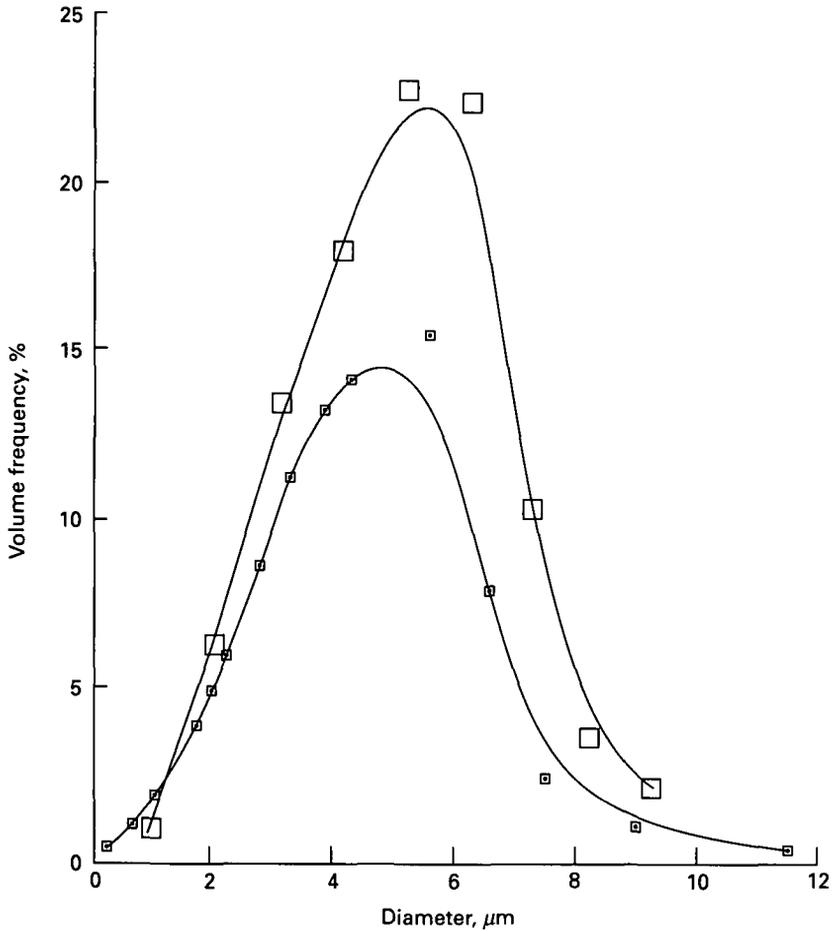


Fig. 5. Size distribution of fat globules in □, camel milk; ◻, cows' milk (Precht *et al.* 1987; Farah & Rügge, 1991).

Table 10. Creaming of camel and cows' milks and of various combinations of their cream and skim milks in 100 ml measuring cylinders at 4 °C†

Sample	Cream layer after 24 h, ml	Fat in lower 50 ml of cylinders after 24 h, %
Cows' milk	12	0.8
Camel milk	1	3.2
Cows' skim + cows' cream	11	0.7
Camel skim + camel cream	1	3.4
Cows' skim + camel cream	7	2.0
Camel skim + cows' cream	3	2.9

† From Farah & Rügge (1991).

was studied in various combinations of skim milks and creams of raw camel and bovine milks. Results of the cream volume and fat percentage obtained are presented in Table 10. All systems that contained skim camel milk creamed poorly. This could be an indication that camel milk lacks the agglutinating substance required to cluster fat globules. The creaming behaviour of camel milk appears to be similar to

Table 11. *Mineral content of camel milk*

(Values are g/l)					
Na	K	Ca	Mg	P	Reference
0.59	1.73	1.15	0.14	0.84	Abu-Lehia (1987)
0.36	0.60	1.32	0.16	0.58	Gnan & Sheriha (1986)
0.36	0.62	1.16	0.08	0.71	Hassan <i>et al.</i> (1987)
0.69	1.56	1.06	0.12	0.63	Mehaia & Al-Kahnal (1989)
(0.35-0.60)†	(1.35-1.55)	(1.00-1.40)	(0.10-0.15)	(0.75-1.10)	

† Values in parentheses are ranges for cows' milk.

that of buffalo and goat milks, which show poor creaming ability owing to an insufficient quantity of agglutinin (Abo-Elnaga *et al.* 1966; Parkash & Jenness, 1968).

Lactose

Lactose is the major carbohydrate in the milk of most mammals and it is generally accepted that non-mammalian sources of lactose are very rare.

Nothing is known about the chemistry and properties of lactose in camel milk. The content in camel milk ranges from 3.4 to 5.6%, slightly higher than the lactose content in cows' milk. Hassan *et al.* (1987) followed the lactose content in camel milk during the lactation period and found minimal variation. Examining the effect of drought on the composition of camel milk, Yagil & Etzion (1980) found that lactose content was low at birth, ~2.8%, but within 24 h there was an increase of 36%. There was a further increase up to 5% as long as drinking water was available. Dehydration led to a decline in the percentage of lactose in the milk until 2.9% was reached. According to the authors this change in lactose concentration would account for the milk being described as sometimes sweet and other times bitter.

Minerals and vitamins

Milk mineral salts are mainly chlorides, phosphates and citrates of Na, Ca and Mg. Although salts comprise < 1% of the milk, they influence the physical state and stability of milk proteins, particularly the caseinate, which are very dependent on the composition of the salt system. The mineral content of camel milk expressed in ash ranges from 0.6 to 0.8%. Little is known about the mineral content of camel milk. Table 11 presents results of analysis for the four principal cationic and one principal anionic constituents. These studies appear to be the only ones in which all these constituents were determined in the same sample. Although the salt composition of milk is influenced by factors such as infection of the udder and stage of lactation, the major salt constituents of camel milk seem to be similar to those of cows' milk. The few available data on chloride and citrate content in camel milk (Yagil & Etzion, 1980; Hassan *et al.* 1987; Farah & Rüegg, 1989) show concentrations similar to those in cows' milk.

Only fragmentary information is available on the vitamin content in camel milk. The data in Table 12 seem to be the only ones in which most vitamins were determined in the same sample. From the results of these studies it appears that camel milk contains less vitamin A and E, thiamin, riboflavin, folic acid and pantothenic acid than cows' milk, while the contents of pyridoxine and vitamin B₁₂ are about the same. The contents of niacin and vitamin C are substantially higher than in cows' milk. In particular the high level of vitamin C in camel milk has been confirmed by several studies (Kon, 1959; Knoess, 1979; Mehaia & Al-Kahnal, 1989;

Table 12. *Vitamin content of camel and cows' milk*

(Values are mg/kg)

Vitamin	Camel milk		Cows' milk	
	Sawaya <i>et al.</i> (1984)	Knoess (1977)	Farah <i>et al.</i> (1992)	Ciba-Geigy (1977)
Vitamin A	0.15	—	0.10	0.17–0.38
Thiamin	0.33	0.60	—	0.28–0.90
Riboflavin	0.42	0.80	0.54	1.2–2.0
Pyridoxine	0.52	—	—	0.40–0.63
Vitamin B ₁₂	0.002	—	—	0.002–0.007
Vitamin E	—	—	0.53	0.2–1.0
Niacin	4.6	—	—	0.5–0.8
Folic acid	0.004	—	—	0.01–0.10
Pantothenic acid	0.88	—	—	2.6–4.9
Vitamin C	24	23	36	3–23

Farah *et al.* 1992). The availability of a relatively large amount of vitamin C (reported range 25–60 mg/l) in camel milk is of significant nutritional relevance in the arid areas where fruits and vegetables containing vitamin C are scarce.

ENZYMIC COAGULATION

Casein micelles in milk can be coagulated by a number of proteolytic enzymes obtained from animal, plant and microbial sources. The proteolytic enzymes traditionally used in the manufacture of cheese are chymosin (EC 3.4.23.4) and pepsin (EC 3.4.23.1), the former extracted from calf stomach and the latter from adult cow stomach.

According to current knowledge (Dalglish, 1982; Brown & Ernstrom, 1988) the clotting process occurs in three stages. In the primary stage the κ -casein of the casein micelles is attacked by the proteinase, to yield two fragments of differing properties—a hydrophilic macropeptide which diffuses away from the micelle after κ -casein splitting, and a hydrophobic para- κ -casein which remains on the micelle. The progressive hydrolysis of κ -casein during the primary stage leads to the alteration of the properties of the casein micelles, such that they become capable of aggregation, and this aggregation phase is the secondary stage of the reaction. In the third stage of the reaction, the aggregate of casein micelles forms a firm gel and syneresis occurs.

There is very little information available on the ability of camel milk to undergo enzymic coagulation and the few available data are often contradictory. Some authors have reported that camel milk cannot be coagulated with rennet unless it is mixed with milk of other species such as goats, ewes or buffaloes (Rao *et al.* 1970; Yagil, 1982). Others reported that camel milk can be coagulated by itself, but a very high dosage of calf rennet is necessary to obtain detectable coagulation (Gast *et al.* 1969; Chapman, 1985).

The most detailed studies—although still far from complete—available for the moment on the subject are the work of Farah & Bachmann (1987), Ramet (1987), Mehaia *et al.* (1988) and Mohamed *et al.* (1989).

Farah & Bachmann (1987) examined the rennet coagulation of ten individual camel milk samples from Northern Kenya using commercial calf rennet powder. The level was adjusted to give a visual coagulation of ~ 5 min in cows' milk. The coagulation properties of camel and bovine milks were measured in a Formagraph according to the procedure of McMahon & Brown (1982). Typical tracings of these

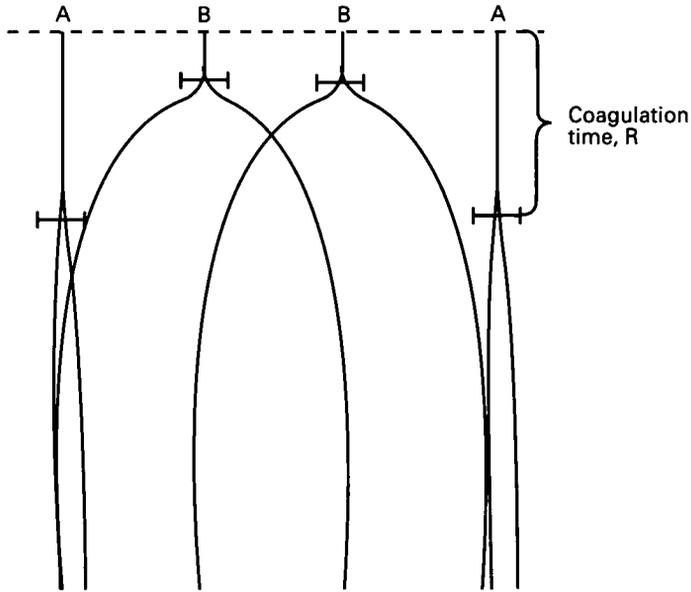


Fig. 6. Formagraph tracings of duplicate camel (A) and cows' (B) milk samples adjusted to pH 6.65; coagulation time, R for cow, 330 s; R for camel, 930 s (Farah & Bachmann, 1987).

milks are shown in Fig. 6. As can be seen, with the same amount of rennet, the coagulation time of camel milk was two to three times longer than that of cows' milk. An advantage of the Formagraph is that the process of curd formation can be recorded. This is expressed as the time from the start of gel development until a width of 20 mm is reached. Following this definition, no curd firmness could be measured in camel milk as this width was never reached.

The effects of temperature, pH and CaCl_2 on coagulation time were also studied. In camel milk, as in cows' milk, coagulation time was reduced with decreasing pH, increasing temperature and added Ca. This means that the response to the changes in pH, temperature and Ca concentration is the same for camel and cows' milks, but the difference in the coagulation times still remains. The rate of liberation of NPN from casein by the action of rennet was measured by monitoring the increase in 12% trichloroacetic acid (TCA)-soluble N compounds. In both camel and cows' milks, the amount of NPN released by the action of rennet increased to a maximum at the coagulation point. However, the increase of NPN as a percentage of total casein N was higher in cows' milk (2%) than in camel milk (1.8%).

Ramet (1987) compared the coagulation by calf rennet powder of pooled Saudi camel milk samples and cows' milk. The powder was diluted to obtain an average clotting time of 13 min. The main emphasis of the investigation was to study the effect of adding CaCl_2 and $\text{Ca}(\text{H}_2\text{PO}_4)_2$ on the clotting of the milks. To coagulate camel milk as quickly as cows' milk, four times as much rennet had to be added. A progressive reduction in clotting time occurred as more salt was added, up to a limiting quantity. The reduction was more marked in cows' milk than camel milk. The study showed that adding Ca salt to camel milk prior to rennet substantially reduced the coagulation time. The author recommends that the amount of Ca salt added be limited to 15 g/100 l. This amount of salt reduces the coagulation time by up to 50% of control times without significantly increasing the bitterness of the cheese.

Immobilized chymosin or pepsin is designed to separate the primary from the secondary phase of the coagulation process. For the primary reaction, cooled milk is passed through a column of the immobilized enzyme. The milk effluent from the column with its κ -casein converted to para- κ -casein is then warmed to start the secondary reaction, allowing coagulation and curd formation (Dalglish, 1982).

Applying this technique, Mehaia *et al.* (1988) studied the mechanism of the primary and the secondary phase of enzymic coagulation of camel milk using soluble and immobilized chymosin. When the pH was lowered from 6.6 to 5.6 about a 5-fold reduction in clotting time was obtained by soluble chymosin as compared with a 4.5-fold reduction with immobilized chymosin. The experiments with soluble chymosin suggest that pH adjustment affected both phases of milk clotting, but use of immobilized chymosin indicated that the secondary phase was influenced to a greater extent by acidification. Mehaia & Cheryan (1983) observed similar results with immobilized pepsin and bovine skim milk. By increasing the Ca concentration from 29 to 50 mM a 4-fold reduction in clotting time was observed at pH 6.6 and a 1.3-fold reduction at pH 5.6, with either soluble or immobilized chymosin. It was confirmed that Ca affects only the secondary phase and not the primary phase of the clotting reaction.

Mohamed *et al.* (1989) studied the coagulation properties of Somali camel milk using chymosin solutions of different concentrations. The coagulation time was two to three times longer than that of cows' milk. With increasing chymosin concentration, the clotting time decreased until it reached a constant value. However, the difference in the coagulation time between camel and cows' milk still remained, and the camel milk coagulum had a lower consistency.

From all these studies it can be concluded that camel milk casein is accessible to chymosin. The action of rennet on camel milk leads to coagulation in the form of flocs but no firm coagulum. The reason for this behaviour is still not known, but the following hypotheses can be considered.

Both the dimension and the composition of the casein micelles are of great importance for the coagulation process. Coagulation time varies with micelle size, and reaches an optimum in the medium and small micelles which have higher κ -casein contents than the large micelles (Ribadeau Dumas & Garnier, 1969; Ekstrand *et al.* 1980). As was pointed out, the size distribution of casein micelles in camel milk is significantly broader than that of cows' milk, with a greater number of larger micelles of 350–500 nm. The poor rennetability could be related to this difference in the size of casein particles, which can affect the availability of κ -casein; it could also be related to the reportedly (Pant & Chandra, 1980; Yagil & Etzion, 1980) low Ca in camel milk, although the distribution of salts between the dissolved and colloidal phases in camel milk is still unknown. The concentration of Ca is crucial for the coagulability of milk casein, and it is well known that the colloidal calcium phosphate in the caseinate micelles is involved in determining whether coagulation occurs when a caseinate system is treated with chymosin (Dalglish, 1982). Milk coagulation is also affected by pH and ionic strength. Anything that alters the ionic environment surrounding the casein micelles influences coagulation.

Until now, calf rennet has been used for clotting camel milk. However, there are some reports that clotting enzyme from a particular species is more effective and specific with milk from the same species. Rennet extracts from lambs were found to be more effective with ewes' milk than with cows' milk (Herian & Krčál, 1971). Pig chymosin and pig pepsin have shown higher milk clotting activity against porcine milk than against bovine milk (Foltmann *et al.* 1981). These results suggest an

Table 13. *Heat denaturation of whey protein of camel and cows' milk*†

Batch no.	Temperature of treatment for 30 min, °C	Whey protein N (WPN), g/kg		Percentage of denatured WPN	
		Cow	Camel	Cow	Camel
1	Raw	0.88	0.77	—	—
	63	0.82	0.65	7	16
	80	0.22	0.50	75	35
	90	0.17	0.41	81	47
2	Raw	0.97	0.93	—	—
	63	0.90	0.81	7	13
	80	0.26	0.63	73	32
	90	0.18	0.49	81	53
3	Raw	0.91	1.00	—	—
	63	0.81	0.85	7	15
	80	0.26	0.67	70	33
	90	0.23	0.49	74	51

† From Farah (1986).

adaptation between the proteolytic specificities of the gastric proteinases and the structure of the caseins. Accordingly, camel rennet could be more effective with camel milk than bovine calf rennet.

To investigate the action of camel rennet on camel milk, Wangoh *et al.* (1993) extracted rennet from abomasa of young cow and camel calves. The clotting activity was determined after extraction and activation. Both camel and bovine abomasal extracts were fractionated and the clotting activity of the fractions compared. Camel rennet coagulated camel milk slightly faster than cows' milk, while bovine rennet extract coagulated camel milk less readily than cows' milk. The chymosin fraction of bovine calf rennet showed weak activity with camel milk while the pepsin fraction coagulated it much more readily than cows' milk. The chymosin fraction of camel rennet coagulated cows' and camel milk equally well, whereas the pepsin fraction had higher clotting activity with camel milk. It is concluded that the coagulation of camel milk by bovine calf rennet is primarily due to its pepsin content. The large variations reported in the capacity of bovine rennet to coagulate camel milk can be explained by the differing pepsin content of the rennet used. Camel milk should therefore be coagulated with camel rennet or pepsin.

EFFECTS OF HEAT ON MILK

Heat processing is not used as a means of preserving camel milk. The heat treatments commonly used for cows' milk such as pasteurization and sterilization cause denaturation of the whey proteins. The phenomenon of denaturation has been extensively studied because of its importance in understanding the changes in the properties of milk that occur with heat treatment (Fox, 1982). However, most of these studies are limited to cows' milk owing to its widespread industrial processing and commercial importance. Farah (1986) studied the effect of heat treatment on the whey proteins of camel milk. Heat denaturation of the whey proteins was compared in camel and cows' milk. The milks were heated to 63, 80 and 90 °C for 30 min and whey proteins in raw and heated milk determined using the Aschaffenburg & Drewry (1959) method for determining N fractions. The whey proteins were also examined by PAGE. Table 13 shows the denaturation of the whey proteins expressed as percentage denaturation relative to the control raw milk. The amount of denatured

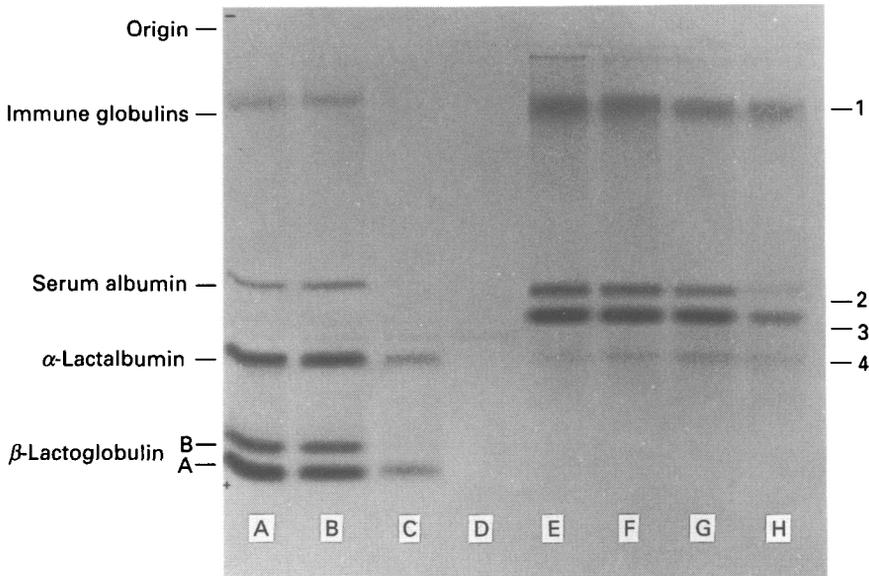


Fig. 7. PAGE patterns of whey protein filtrates prepared from camel and cows' milk heated for 30 min at various temperatures. Cows' milk: A, raw; and heated at B, 63 °C; C, 80 °C; D, 90 °C. Camel milk: E, raw; and heated at F, 63 °C; G, 80 °C; H, 90 °C. (Farah, 1986).

whey proteins in the cows' milk was in agreement with reported values (Larsson & Rolleri, 1955; Melachouris & Tuckey, 1966). The lowest time-temperature combination (63 °C, 30 min, which represents the conditions of conventional pasteurization) caused little whey protein denaturation, while stronger heat treatment (80 °C, 30 min, which is more extreme than pasteurization) resulted in 70–81 % denaturation of the whey proteins.

The camel milk whey protein was generally more heat-stable than that in cows' milk. The degree of denaturation of the whey proteins during heating varied in camel milk from 32 to 35 % at 80 °C and from 47 to 51 % at 90 °C. The heat stability of camel whey proteins could be confirmed by means of PAGE.

Fig. 7 gives the whey protein gel patterns of raw and heated cows' and camel milks. The electrophoretic pattern obtained for the individual whey proteins in cows' milk agrees with reported findings (Akroyd, 1968). Pasteurization temperature (63 °C) caused no visible change in the whey protein gel pattern. At 80 °C (lane C) immunoglobulins and serum albumin disappeared from the electrophoresis pattern. Portions of β -lactoglobulins (A and B) and α -lactalbumin remained undenatured at 80 °C, but disappeared after heat treatment at 90 °C (lane D).

The main protein bands of camel milk are designated by the numbers 1, 2, 3 and 4. The electrophoretic patterns in lanes E, F and G show one faint band in the upper region of the gel (component 1) followed by two sharp bands and one faint band in the lower part of the gel (components 2, 3 and 4). The gel patterns indicate that a pronounced heat effect can be observed only in the 90 °C sample (lane H), where band intensities decrease without totally disappearing.

In order to study the ability of camel milk to withstand higher processing temperatures, the heat coagulation time (HCT) was studied (Farah & Atkins, 1992).

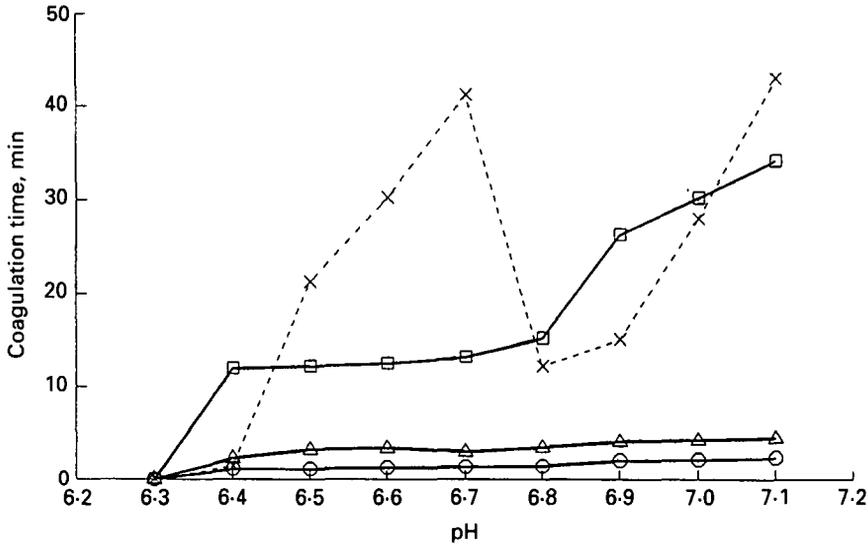


Fig. 8. Heat coagulation time-pH curves for camel milk at \square , 100 °C; Δ , 120 °C and \circ , 130 °C; and for cows' milk at 130 °C (\times) (Farah & Atkins, 1992).

The heat stability of milk can be defined in terms of the time required to induce coagulation at a given temperature. For bovine milk, the most widely used temperature for heat coagulation is 130 or 140 °C. Preliminary experiments showed that in camel milk the HCT at 140 °C was too short (< 1 min) for the assay. HCT was therefore determined at 100, 120 and 130 °C according to the method of Davies & White (1966). Milk was adjusted to various pH in the range 6.5–7.1.

Fig. 8 shows the HCT-pH curves for pooled camel and cows' milks. The shape of the HCT-pH curve for camel milk at low temperature was different from those at high temperatures. The milks heated at 130 and 120 °C were very unstable at all pH values and coagulated in 2–3 min. At 100 °C the heat coagulation time initially increased, then remained constant between pH 6.4 and 6.7 and increased progressively with increasing pH.

The HCT-pH curve in cows' milk is in agreement with reported findings (Rose, 1963; Fox, 1982). It shows a maximum around pH 6.7 and minimum near pH 6.8. The heat stability increases above 6.9. This type of curve, with pronounced stability maximum and minimum, is called type A. Most cows' milk exhibits type A behaviour, but there are some milks (type B) that give a curve with no maximum or minimum (Fox, 1982).

Considerable interspecies differences in the shape of HCT-pH curves have been reported. The heat stability of individual porcine milks is very low and shows a progressive increase with increasing pH (Hoynes & Fox, 1975). Ovine and caprine milks show a marked maximum at pH 7.0 in their HCT-pH curves and are very unstable at all higher pH values (Fox & Hoynes, 1976). Milk from some mares has a HCT-pH curve of a shape similar to that of ovine and caprine milks, while others show a pH response similar to that of porcine milk (Fox & Hoynes, 1976).

The reason for the different heat stabilities in different species is still not well established. However, the importance of β -lactoglobulin and κ -casein interaction in determining the shape of the HCT-pH curve was confirmed by Tessier & Rose (1964), who showed that the minimum in the HCT-pH curve of a type A milk is eliminated

on enrichment with κ -casein. Conversely a type B milk is converted to a type A milk by removing some of the micellar κ -casein. Tessier & Rose (1964) concluded that the heat stability pattern of milk is controlled by the proportions of surface κ -casein and soluble β -lactoglobulin present.

No protein homologous to κ -casein has yet been clearly detected in camel milk. It is possible that camel casein contains so very little κ -casein that it escaped detection or was obscured by other casein fractions. On the other hand, there is still no evidence for the presence of β -lactoglobulin in camel milk (Beg *et al.* 1984, 1987). The lack or deficiency of these two proteins in camel milk may be a cause of its poor stability at high temperatures, but this remains to be confirmed.

ANTIBACTERIAL ACTIVITY

Camel milk is mainly consumed in the raw state by nomads. It may therefore be of interest to determine the activity of natural antimicrobial proteins in camel milk. Moreover there are reports that camel milk could have medicinal properties, which suggests that it contains antimicrobial components.

The ability of camel milk to inhibit growth of pathogenic bacteria and its relation to whey lysozyme have been studied by Barbour *et al.* (1984). Twenty of 200 samples collected from individual camels inhibited growth of one or more of six pathogenic test organisms. The milk samples with inhibitory properties scored zero in the California mastitis test. The lysozyme content of the 20 samples showing growth inhibition was 648 $\mu\text{g}/100$ ml, significantly higher than the average in the 38 samples (62.6 $\mu\text{g}/100$ ml) that had no inhibition effect. The reported average lysozyme content of human milk is 40000 $\mu\text{g}/100$ ml and for cows' milk 120 $\mu\text{g}/100$ ml (Chandan *et al.* 1968). Lysozyme is a milk protein that has bactericidal effect as it is capable of degrading the bacterial cell wall and enhancing the activity of the immune antibodies. Its reported high level in camel milk is very significant and needs further elucidation.

El Sayed *et al.* (1992) extracted lysozyme, lactoferrin, lactoperoxidase, immunoglobulin G and immunoglobulin A from camel milk. The activity of these protective proteins was assayed against *Lactococcus lactis* subsp. *cremoris*, *Escherichia coli*, *Staphylococcus aureus*, *Salmonella typhimurium* and rotavirus. The antibacterial activity spectrum of camel milk lysozyme was similar to that of egg white lysozyme and different from the lysozyme of bovine milk. Bovine and camel milk lactoferrin antibacterial activity spectra were similar. Camel milk lactoperoxidase was bacteriostatic against the Gram-positive strains and bactericidal against Gram-negative cultures. The immunoglobulins had little effect against the bacteria but high titres of antibodies against rotavirus were found in camel milk.

CONCLUSIONS

In spite of its economic and ecological advantages the virtues of the camel are almost unknown outside the communities where it is used and until now it has received less attention than other domestic animals.

Research on camel milk was until the early 1970s limited to studies on general composition and milk yields. Since the early 1980s interest in studies on physicochemical properties of camel milk as well as technological problems associated with its utilization has been growing. However, such studies are still fragmentary and by no means systematic. Much of the work so far has been carried out by

individuals with little institutional support. Thus the research has tended to remain isolated with little impact on dairy camel production. The wide dispersal of pastoralists in the arid areas certainly made it difficult to develop a proper camel dairy research. The aim of the present review has been to bring together as much information as possible on the properties of camel milk.

REFERENCES

- ABDEL-RAHIM, A. G. 1987 *World Review of Animal Production* **23**(1) 9–12
- ABO-ELNAGA, I. G., EL-SADEK, G. M. & EL-SOKARY, A. M. 1966 *Milchwissenschaft* **21** 210–215
- ABU-LEHIA, I. H. 1987 *Milchwissenschaft* **42** 368–371
- ABU-LEHIA, I. H. 1989 *Food Chemistry* **34** 261–272
- ABU-LEHIA, I. H., AL-MOHIZEA, I. S. & EL-BEHERY, M. 1989 *Australian Journal of Dairy Technology* **44** 34–36
- AKROYD, P. 1968 In *Chromatographic and Electrophoretic Techniques*, vol. 2, *Zone Electrophoresis*, 2nd edn, pp. 399–413 (Ed. I. Smith). London: William Heinemann Medical Books
- ALI, M. Z. & ROBINSON, R. K. 1985 *Journal of Dairy Research* **52** 303–307
- ASCHAFFENBURG, R. 1963 *Journal of Dairy Research* **30** 259–260
- ASCHAFFENBURG, R. & DREWRY, J. 1959 *15th International Dairy Congress*, London **3** 1631–1637
- BARBOUR, E. K., NABBUT, N. H., FRERICHS, W. M. & AL-NAKHLI, H. M. 1984 *Journal of Food Protection* **47** 838–840
- BAYOUMI, S. 1990 *Kieler Milchwirtschaftliche Forschungsberichte* **42** 3–8
- BEG, O. U., VON BAHR-LINDSTRÖM, H., ZAIDI, Z. H. & JÖRNVALL, H. 1984 *Bioscience Reports* **4** 1065–1070
- BEG, O. U., VON BAHR-LINDSTRÖM, H., ZAIDI, Z. H. & JÖRNVALL, H. 1985 *European Journal of Biochemistry* **147** 233–239
- BEG, O. U., VON BAHR-LINDSTRÖM, H., ZAIDI, Z. H. & JÖRNVALL, H. 1986 *European Journal of Biochemistry* **159** 195–201
- BEG, O. U., VON BAHR-LINDSTRÖM, H., ZAIDI, Z. H. & JÖRNVALL, H. 1987 *FEBS Letters* **216** 270–274
- BREMAUD, O. 1969 [*Notes on Camel Production in the Northern Districts of the Republic of Kenya.*] 105pp. Maisons-Alfort: Institut de l'Élevage et des Médecins Vétérinaires des Pays Tropicaux
- BROWN, R. J. & ERNSTROM, C. A. 1988 In *Fundamentals of Dairy Chemistry*, 3rd edn, pp. 609–633 (Ed. N. P. Wong), New York: Van Nostrand Reinhold
- BULLIET, R. W. 1975 *The Camel and the Wheel*. Cambridge, MA: Harvard University Press
- BÜRGEMEISTER, R. 1974 [*Problems of Dromedary Behaviour and Husbandry in South Tunisia.*] 95pp. Dissertation, Institut für Tropische Veterinärmedizin, Giessen
- CAUVET, G. 1925 *Les Chameaux*. Paris: Baillière
- CHANDAN, R. C., PARRY, R. M. & SHAHANI, K. M. 1968 *Journal of Dairy Science* **51** 606–607
- CHAPMAN, M. J. 1985 *World Animal Review* no. 55 14–19
- CIBA-GEIGY 1977 *Wissenschaftliche Tabellen*, p. 211. Basel: Ciba-Geigy AG
- COLE, D. P. 1975 *Nomads of the Nomads: the Almurrah Bedouin of the Empty Quarter*. Chicago, IL: Aldine Publishing Corporation
- CONTI, A., GODOVAC-ZIMMERMANN, J., NAPOLITANO, L. & LIBERATORI, J. 1985 *Milchwissenschaft* **40** 673–675
- DALGLEISH, D. G. 1982 In *Developments in Dairy Chemistry—1 Proteins*, pp. 157–187 (Ed. P. F. Fox). London: Applied Science Publishers
- DAVIES, D. T. & WHITE, J. C. D. 1966 *Journal of Dairy Research* **33** 67–81
- DESAI, H. K., PATEL, J. N., PANDYA, A. J., UPADHYAY, K. G. & VYAS, S. H. 1982 *Gujarat Agricultural University Research Journal* **7** 131–132
- DHINGRA, D. R. 1934 *Biochemical Journal* **28** 73–78
- EIGEL, W. N., BUTLER, J. E., ERNSTROM, C. A., FARRELL, H. M., HARWALKAR, V. R., JENNESS, R. & WHITNEY, R. MCL. 1984 *Journal of Dairy Science* **67** 1599–1631
- EKSTRAND, B., LARSSON-RAŹNIKIEWICZ, M. & PERLMANN, C. 1980 *Biochimica et Biophysica Acta* **630** 361–366
- EL-AMIN, F. M. 1979 *IFS (International Foundation for Science) Provisional Reports* no. 6 35–54
- EL-BAHAY, G. M. 1962 *Veterinary Medical Journal* **8**(9) 7–18
- EL-SAYED, I., EL-AGAMY, S. I., RUPPANNER, R., ISMAIL, A., CHAMPAGNE, C. P. & ASSAF, R. 1992 *Journal of Dairy Research* **59** 169–175
- FAO 1979 *Statistical Yearbook*. Rome: FAO
- FARAH, Z. 1986 *Milchwissenschaft* **41** 763–765
- FARAH, Z. & ATKINS, D. 1992 *Journal of Dairy Research* **59** 229–231
- FARAH, Z. & BACHMANN, M. R. 1987 *Milchwissenschaft* **42** 689–692
- FARAH, Z. & FARAH-RIESEN, M. 1985 *Milchwissenschaft* **40** 669–671
- FARAH, Z., RETTENMAYER, R. & ATKINS, D. 1992 *International Journal of Vitamin and Nutrition Research* **62** 30–33
- FARAH, Z. & RÜEGG, M. W. 1989 *Food Microstructure* **8** 211–216
- FARAH, Z. & RÜEGG, M. 1991 *Journal of Dairy Science* **74** 2901–2904
- FARAH, Z., STREIFF, T. & BACHMANN, M. R. 1989 *Milchwissenschaft* **44** 412–414

- FIELD, C. R. 1979 *IFS (International Foundation of Science) Provisional Report* no. 6 215–240
- FOLTMANN, B., JENSEN, A. L., LONBLAD, P., SMIDT, E. & AXELSEN, N. H. 1981 *Comparative Biochemistry and Physiology* **68B** 9–13
- FOX, P. F. 1982 In *Developments in Dairy Chemistry—1 Proteins*, pp. 189–228 (Ed. P. F. Fox). London: Applied Science Publishers
- FOX, P. F. & HOYNES, M. C. T. 1976 *Journal of Dairy Research* **43** 433–442
- GAST, M., MAUBOIS, J. L. & ADDA, J. 1969 *Le Lait et Les Produits Laitiers en Ahaggar*. Paris: Centre de Recherches en Anthropologie Préhistorique et Ethnologie
- GAUTHIER-PILTERS, H. & DAGG, A. I. 1981 *The Camel. Its Evolution, Ecology, Behavior and Relationship to Man*. Chicago, IL: University of Chicago Press
- GLASS, R. L., TROOLIN, H. A. & JENNESS, R. 1967 *Comparative Biochemistry and Physiology* **22** 415–425
- GNAN, S. O. & SHERIHA, A. M. 1986 *Australian Journal of Dairy Technology* **41** 33–35
- GOUDA, A., EL-ZAYAT, A. & EL-SHABRAWY, S. A. 1984 *Annals of Agricultural Science* **29** 755–762
- HAGRASS, A. E., HASSAN, A. A., SORYAL, K. A., MERVAT, A. S. & EL-SHABRAWY, S. A. 1987 *Egyptian Journal of Food Science* **15** 15–25
- HARTLEY, B. J. 1979 *IFS (International Foundation for Science) Provisional Reports* no. 6 109–123
- HASSAN, A. A., HAGRASS, A. E., SORYAL, K. A. & EL-SHABRAWY, S. A. 1987 *Egyptian Journal of Food Science* **15** 1–14
- HERIAN, K. & KRČÁL, Z. 1971 *Průmysl Potravin* **22** 137–139
- HIPP, N. J., GROVES, M. L., CUSTER, J. H. & McMEEKIN, T. L. 1952 *Journal of Dairy Science* **35** 272–281
- HOYNES, M. C. T. & FOX, P. F. 1975 *Journal of Dairy Research* **42** 43–56
- KIWUWA, G. H. 1973 *East African Agricultural & Forestry Journal* **39** 110–119
- KNOESS, K. H. 1977 *World Animal Review* No. 22 39–44
- KNOESS, K. H. 1979 *IFS (International Foundation for Science) Provisional Reports* no. 6 109–123
- KNOESS, K. H., MAKHUDUM, A. J., RAFIQ, M. & HAFEZ, M. 1986 *World Animal Review* no. 57 11–21
- KON, S. K. 1959 *Milk and Milk Products in Human Nutrition*. Rome: FAO (FAO Nutrition Studies no. 17, p. 6)
- LARSON, B. L. & ROLLERI, G. D. 1955 *Journal of Dairy Science* **38** 351–360
- LARSSON-RAŹNIKIEWICZ, M. & MOHAMED, M. A. 1986 *Swedish Journal of Agricultural Research* **16** 13–18
- McMAHON, D. J. & BROWN, R. J. 1982 *Journal of Dairy Science* **65** 1639–1642
- MEHAIA, M. A., ABOU EL-KHEIR, A. M. & HABLAS, M. A. 1988 *Milchwissenschaft* **43** 438–441
- MEHAIA, M. A. & AL-KAHNAL, M. A. 1989 *Nutrition Reports International* **39** 351–357
- MEHAIA, M. A. & CHERYAN, M. 1983 *Milchwissenschaft* **38** 137–140
- MELACHOURIS, N. P. & TUCKEY, S. L. 1966 *Journal of Dairy Science* **49** 1154–1156
- MOHAMED, M. A., MURSAL, A. I. & LARSSON-RAŹNIKIEWICZ, M. 1989 *Milchwissenschaft* **44** 278–280
- MORRISON, W. R. 1968a *Lipids* **3** 107–110
- MORRISON, W. R. 1968b *Lipids* **3** 101–103
- MORRISON, W. R., JACK, E. L. & SMITH, L. M. 1965 *Journal of the American Oil Chemists' Society* **42** 1142–1147
- MULDER, H. & WALSTRA, P. 1974 *The Milk Fat Globule: emulsion science as applied to milk products and comparable foods*, p. 147. Farnham Royal: Commonwealth Agricultural Bureaux
- PANT, R. & CHANDRA, P. 1980 *Milchwissenschaft* **35** 91–93
- PARKASH, S. & JENNESS, R. 1968 *Dairy Science Abstracts* **30** 67–87
- PRECHT, D., PETERS, K. H. & PETERSEN, J. 1987 *Milchwissenschaft* **42** 776–781
- RAMET, J. P. 1987 *World Animal Review* no. 61 11–16
- RAO, C. K. 1974 *Scheme for the Improvement of Indian Camels: to what extent camels are milked and what the approximate yield is*. New Delhi: Mimeo Item no. 12
- RAO, M. B., GUPTA, R. C. & DASTUR, N. N. 1970 *Indian Journal of Dairy Science* **23** 71–78
- RENNER, E. 1991 *Dictionary of Milk and Dairying*, p. 12. München: Volkswirtschaftliche Verlag
- RIBADEAU DUMAS, B. & GARNIER, J. 1969 *Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences D Sciences Naturelles* **268** 2504–2506
- ROSE, D. 1963 *Dairy Science Abstracts* **25** 45–52
- ROWLAND, S. J. 1938 *Journal of Dairy Research* **9** 30–41
- RÜEGG, M. & BLANC, B. 1982 *Food Microstructure* **1** 25–47
- SAWAYA, W. N., KHALIL, J. K., AL-SHALHAT, A. & AL-MOHAMMAD, H. 1984 *Journal of Food Science* **39** 744–747
- SCHMIDT-NIELSEN, K. 1964 *Desert Animals: physiological problems of heat and water*. Oxford: University Press
- SESTUCHEVA, V. 1958 *Molochnaya Promyshlennost'* **19** 33–39
- SHALASH, M. R. 1979 *IFS (International Foundation for Science) Provisional Reports* no. 6 285–290
- SIMPSON, G. G. 1945 *The Principles of Classification and a Classification of Mammals*. New York: American Museum of Natural History (*Bulletin* **85** 1–350)
- SPENCER, P. 1973 *Nomads in Alliance: symbiosis and growth among the Rendille and Sambutu of Kenya*, 230 pp. London: Oxford University Press
- TESSIER, H. & ROSE, D. 1964 *Journal of Dairy Science* **47** 1047–1051
- URBISINOV, Zh. K., SERVETNIK-CHALAYA, G. K. & IZATULLAEV, E. A. 1981 *Voprosy Pitaniya* no. 6 41–42 (*Dairy Science Abstracts* **45** 693)
- WAHBA, A., EL-ABBASSY, F., ISMAIL, I. & EL-AGAMY, S. I. 1988 *Egyptian Journal of Dairy Science* **16** 19–22

- WANGO, J., FARAH, Z. & PUHAN, Z. 1993 *Milchwissenschaft* **48** 322–325
- WHITNEY, R. MCL., BRUNNER, J. R., EBNER, K. E., FARRELL, H. M., JOSEPHSON, R. V., MORR, C. V. & SWAISGOOD, H. E. 1976 *Journal of Dairy Science* **59** 795–815
- WILSON, R. T. 1984 *The Camel*. Harlow: Longman Group
- YAGIL, R. 1982 *Camels and Camel Milk*. Rome: FAO (*FAO Animal Production and Health Paper* no. 26)
- YAGIL, R. 1985 *The Desert Camel. Comparative Physiological Adaptation*. Basel: Karger
- YAGIL, R. & ETZION, Z. 1980 *Journal of Dairy Research* **47** 159–166
- ZEUNER, F. E. 1963 *A History of Domesticated Animals*. London: Hutchinson