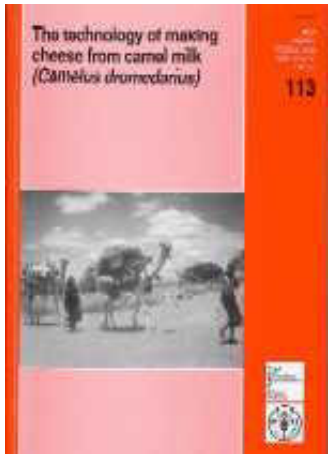

The technology of making cheese from camel milk (*Camelus dromedarius*)

FAO
ANIMAL
PRODUCTION
AND HEALTH
PAPER

113

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Food and Agriculture Organization of the United Nations
Rome, 2001

Contents

Research has shown that the camel is the most efficient domestic animal for converting vegetative matter into work, milk and meat. Camel milk is already used for human consumption, in its fresh or fermented forms or as butter, but only rarely as cheese.

Camel milk is more technically difficult to process than milk from other domestic animals and some researchers have even claimed that camel milk cheese would be impossible to produce. However, if normal cheese-making procedures are adapted to camel milk's particular characteristics, satisfactory cheeses can be made. The technology of making cheese from camel milk describes the composition of camel milk, compares it with other milks and explains how it can be used to make cheese.

ISBN 92-5-103154-1

Introduction

THE IMPORTANCE OF THE CAMEL IN ARID REGIONS

The image of the camel, symbol of human survival in the desert, is tied to the history of the major nomadic civilizations of the hot dry areas of the northern hemisphere. The camel embodies one of the essential elements of the culture and agriculture of these regions.

Geographically, the camel is distributed throughout the tropical and subtropical dry zones of North Africa, western Asia and northwest India (Figure 1). The limits of its natural distribution are determined by wet climates and the presence of the tsetse fly. Camels were introduced into Australia on a large scale during the last century. Isolated introductions took place in parts of the United States of America, Central America, the Caribbean, southern Africa and Europe (Wilson, 1984; Wilson, Araya and Melaku, 1990).

The camel is the ideal domestic animal in deserts with long, dry, hot periods of eight months or more and scarce, erratic annual rainfalls between 50 and 550 mm.

The camel is used for several purposes for which its role is essential. It is used as a

beast of burden for transporting goods and people as well as for providing milk. Milk is often the only regular food source for its owners. The camel's meat, wool and leather are also widely utilized. In some parts of East Africa, the animal is bled regularly and its blood consumed fresh or mixed with milk. The camel is universally highly valued and provides social standing for its owner.

The chief role of the camel relates directly to its remarkable adaptation to extremely harsh conditions. It can flourish where no other domestic animal can survive. This exceptional ability is the result of several anatomical and physiological characteristics. Where green forage is available in mild climates, the camel may go several months without drinking. Under very hot conditions, it may drink only every eight to ten days and lose up to 30 percent of its body weight through dehydration (Yagil and Etzion, 1980; Yagil, 1982; Wilson, 1984; Yagil, 1985; Ramet, 1987).

This remarkable attribute results from a very low basal metabolism and several water-conserving adaptations. Water losses by respiration and perspiration are low because of the camel's ability to withstand, without apparent difficulty, large variations in body temperature of up to 6°C. Excess heat accumulated during the heat of the day or after hard work is later lost by conduction, convection and radiation when the animal is at rest or when the atmosphere cools down at night. Moreover, the water lost by respiration and perspiration is low compared with the body weight of the animal. Water loss in the faeces and urine is also very limited (Wilson, 1984; Yagil, 1986). The morphology of the animal, characterized by the length of the neck and limbs and by the conical shape of the abdomen, creates a large surface area that improves heat transfer. General thermal conductivity also appears to be enhanced by the location of fatty tissues in the hump (Wilson, 1984; Yagil, 1986).

Another limitation imposed by arid conditions is the sparse and poor quality of pastures. Compared with other ruminants, the camel is distinguished by the high diversity of its diet. It can feed on herbaceous plants, shrubs, shoots, cacti and date stones. During the dry season, it often has to survive on thorny, withered plants low in protein but rich in fibre and cellulose (Peyre de Fabregues, 1989). According to the little research on the subject, it appears that the camel assimilates nitrogen and cellulose better than any other mammal (CIHEAM, 1988; Kamoun, Girard and Bergaoui, 1989; Gérard and Richard, 1989).

This high efficiency in assimilating cellulose appears to be related to a specific mastication process that induces improved impregnation of saliva into the bolus. The location of aquiferous cells on the stomach wall permits better wetting of feed during rumination and improves intake of some soluble elements. In addition, it seems that the stomach can retain coarse particles and allow only the smallest elements to pass through the intestine wall, which increases digestive recovery (Yagil, 1985; Yagil, 1986).

Another distinguishing feature is the camel's highly efficient system of recycling urea to meet its nitrogen requirements and to balance the low content of this element in desert plants. Unlike other mammals, camels have a distinctive kidney structure that considerably reduces the removal of urea in urine. The removal of blood urea is effected by selective permeability of the stomach and intestinal walls. Later, this urea is assimilated by the stomach microflora in the cavities to ensure protein synthesis (Wilson, 1984; Yagil, Saran and Etzion, 1984; Yagil, 1985).

In 1985, the world camel population was estimated at about 16.5 million, with more than 80 percent of the world herd in Africa. Somalia and the Sudan have the largest populations, with some 70 percent of the African herd. In Asia, about 70 percent are

spread over the Indian subcontinent (Wilson, Araya and Melaku, 1990).

Historical trends in worldwide numbers are difficult to track because of lack of reliable data. It appears, however, that a decrease in numbers was observed from 1950 to 1980. Several causes were responsible, including mechanization of transport, sedentarization of nomads and exceptional droughts. Over the last decade, with the exception of a few isolated cases, a new phase in the development of the camel can be noted (Table 1). This is the result of several factors, mainly an increasing demand for milk and meat as a consequence of large human population increases in the areas involved. Other factors are associated with the extension of the desert in the Sahel region and increased utilization of camels as pack and work animals in countries where the cost of fuel is high. A further reason for this resurgence is the effect of recent technical and scientific research (Wilson, Araya and Melaku, 1990; Farah, 1993). This work has shown that the camel is the most efficient domestic animal for converting vegetative matter into work, milk and meat in hot arid areas. Recent advances in understanding camel pathology and physiology in relation to its products have led to better understanding of breeding and processing methods (Hoste, Peyre de Fabregues and Richard, 1985; Higgins, 1986; Marie, 1987; OIE, 1987; IEMVT, 1989; CIHEAM, 1989; Wilson, Araya and Melaku, 1990; Farah, 1993).

CAMEL MILK PRODUCTION

Existing data on the milk yield of camels are numerous but highly variable. According to results from several authors, lactation periods vary from 9 to 18 months, with annual milk yields of between 800 and 3 600 litres. Mean daily milk production is reported to

range from 2 to 6 litres under desert conditions and up to 12 to 20 litres under more intensive breeding systems. These large differences can be explained by the fact that measurements have often been made under local conditions without taking into account local factors that might influence milk production. Furthermore, camel breeds or individual animals probably exist with significantly different milk-producing potential that has not been fully exploited because the selective pressure of humans on the camel has been minimal compared with other domestic animals (Richard and Gérard, 1989).

Nutritional factors also influence milk production. Diets enriched with green forages such as alfalfa, bersim or cabbage greatly increase milk yield (Knoess, 1977; Knoess *et al.*, 1986; Richard and Gérard, 1989). The amount of milk is only marginally decreased when drinking-water is restricted, while total solids are significantly lowered (Yagil and Etzion, 1980; Yagil, Saran and Etzion, 1984; Ramet, 1987; Farah, 1993). This milk dilution is a physiological response to heat and could be a natural adaptation to provide much-needed water to the dehydrated calf (Yagil, Saran and Etzion, 1984; Farah, 1993).

Studies concerning the development of milk quantity as a function of stage of lactation indicate little correlation. Lactation curves in fact indicate large differences compared with other lactating mammals. Some curves indicate low yields during the first half of the lactation period and an increase in the second. Other results report higher yields at the beginning, followed by falls towards the end. Occasionally, one or two distinct peaks can be observed or, conversely, steady production throughout the lactation (Field, 1979; Bachmann and Schulthess, 1987; Ellouze and Kamoun, 1989; Richard and Gérard, 1989; Martinez, 1989). The high disparity between these various sets of data can probably be explained by differences in genetic potential, climate, feeding conditions and sampling techniques.

Milking practice also affects the amount of milk. Generally, the calf is allowed to suckle for a few minutes before hand milking. The actual volume of milk secreted is therefore difficult to measure. If milking is performed without any previous mechanical stimulation of the mammary gland, lower yields are observed. Milking must be done by a person who is well known to the camel. When the usual milker is changed, significant milk retention is often observed. It also appears that milking frequency influences daily milk yield. Generally, animals are milked two to four times a day (Hartley, 1980; Ramet, 1987; Martinez, 1989; Abeiderrahmane, 1994) but sometimes as many as six or seven times (Knoess, 1977). Changing the milking frequency from two to four operations increased milk production from one to 1.5 litres a day (Evans and Powys, 1980).

COMPOSITION OF CAMEL MILK

General composition

Publications dealing with the composition of camel milk are relatively scarce and much of the information is approximate and fragmentary. Table 2 therefore indicates only the more important data published in review articles by several authors (Yagil, 1982; Wilson, 1984; Wilson, Araya and Melaku, 1990; Farah, 1993). More recent results have been added.

Table 2 shows a fairly wide range of values for the main constituents of camel milk. As mentioned above for milk yields, this diversity could be mainly related to the different genetic potential of breeds, to varying physiological and feeding conditions or to stage of lactation. The computed mean value indicates that the total solids content of camel milk is slightly lower than cow's milk.

The most important factor affecting the overall composition of camel milk is water content. It has been clearly demonstrated that experiments which restricted drinking-water caused an increase in water content and a subsequent decrease in total solids (Yagil and Etzion, 1980; Yagil, 1986; Yagil, Amir, Abu-Ribaya and Etzion, 1986). Seasonal climatic variations and water and feed availability had a similar effect (Knoess *et al.*, 1986; Ramet, 1987; Ramet, 1994a).

The main constituents

Although the overall composition of camel milk is similar to cow's milk, some differences exist in the molecular composition of proteins and lipids and in the mineral balance.

Protein. **The average mean composition of the protein and nitrogen fractions of camel milk are generally similar to those of cow's milk. The average values for the casein and whey protein contents vary from 1.9 to 2.3 percent and 0.7 to 1.0 percent respectively. The nitrogen content of casein is a little lower than cow's milk, reaching 71 to 79 percent of total protein nitrogen compared with 77 to 82 percent (Jenness and Sloan, 1969; Mehaia, 1987; Farah, 1993).**

Casein fractions have been isolated in camel milk and found to be homologous with bovine casein. The balance between the different casein fractions is very different, however, and chiefly identified by a low amount of kappa casein of only about 5 percent of the total casein, compared with about 13.6 percent in bovine casein (Table 3; Jardali, 1988; Jardali and Ramet, 1991; Farah, 1993). The molecular weights and amino acid composition of the casein fractions differ from those of cow's milk (Table 4; Sawaya *et al.*, 1984; Larsson-Raznikiewicz and Mohamed, 1986; Farah and Ruegg, 1989; Mohamed,

1990; Farah, 1993).

The state of the casein micelle structure has seldom been investigated. Most results, however, conclude that the size distribution of casein particles in camel milk is significantly broader than in cow's milk, exhibiting a greater number of large particles. The average micelle diameter of camel milk was found to be about double that of cow's milk at 320 nm and 160 nm respectively (Table 4; Sawaya *et al.*, 1984; Larsson-Raznikiewicz and Mohamed, 1986; Farah and Ruegg, 1989; Jardali and Ramet, 1991; Jardali, 1994).

The quantity of whey proteins is higher in camel milk than cow's milk, at 0.9 to 1.0 percent and 0.7 to 0.8 percent respectively. Individual fractions have been identified according to chromatographic and electrophoretic mobility and to the primary sequence of their amino acid chains. Two types of alpha-lactalbumin similar to bovine milk have been isolated. Beta-lactoglobulin has not been clearly identified (Conti *et al.*, 1985; Beg *et al.*, 1987; Farah, 1986). Two novel camel whey proteins, unlike any known bovine milk whey proteins, have been separated and characterized (Beg *et al.*, 1987). The heat stability of camel milk whey proteins was found to be considerably higher than in cow's milk (Farah,1986; Farah and Atkins, 1992).

Lactose. **Table 2 indicates that the average lactose content of camel milk is slightly lower (4.62 percent) than cow's milk (4.80 percent). It seems, however, that the variability is higher, with extreme values between 2.90 to 5.80 percent in camel milk compared with 4.40 to 5.80 percent in cow's milk (Webb, Johnson and Alford, 1974).**

Lipids. **A bibliographic review indicates that the fat content of camel milk varies greatly from 1.10 to 5.50 percent depending on the breed and feeding conditions, the average**

being the same as for cow's milk (Table 2). Studies on the structure and composition of fat globules revealed two main characteristics:

- **Whereas previous results have found small fat particles in camel milk (Gouda, El-Zahat and El-Shabrawy, 1984; Knoess *et al.*, 1986), more recent work indicates that fat globule size distribution is similar to cow's milk, with an average of 2.9 micrometres (Wahda *et al.*, 1988; Farah and Ruegg, 1991; Farah, 1993). The fat globule membrane appears to be thicker than in other types of milk and closely bound to the proteins (Rao, Gupta and Dastur, 1970; Knoess *et al.*, 1986; Farah, Streiff and Bachmann, 1990; Farah and Ruegg, 1991). The creaming properties of camel milk fat globules are poor, resulting from a deficiency in agglutinin that causes a very slow creaming rate at all temperatures (Farah and Ruegg, 1991).**
- **A factor specific to camel milk fat is the low percentage of short-chain C4 to C12 fatty acids. The concentration of long-chain fatty acids such as palmitic and stearic are, however, relatively high (Table 6). As a consequence, the physical properties of the triglycerides are characterized by much higher melting and crystallization points than cow's milk (Abu-Leiha, 1987; Abu-Leiha, 1989; Farah, Streiff and Bachmann, 1989; Farah and Ruegg, 1991; Abu-Leiha, 1994).**

Minerals. **Table 7 indicates the mineral content of camel milk of various origins as measured by several authors. The mean values show that the concentrations of the major salts are slightly lower than cow's milk.**

It appears that the salt balance between the soluble and the colloidal forms of calcium, phosphorus and magnesium is very similar to that measured in cow's milk. The percentage of the soluble fractions reaches 30 percent of the total content (Farah and Ruegg, 1989). It also seems that the proportion of soluble calcium and phosphorus

increases up to 61 and 75 percent respectively when milk is collected in the hot season from animals managed along traditional extensive lines.

Vitamins. **The vitamin content of camel milk differs from cow's milk in that it includes a higher level of vitamin C and niacin (Table 8). Conversely, the amount of vitamin A is much lower, varying between 12.9 IU/100 g (Ahmed, Awad and Fahmy, 1977) and 50.0 IU/100 g (Sawaya *et al.*, 1984). Because only incomplete information is available on the vitamin content of camel milk, the figures mentioned above should be treated with caution.**

SUMMARY OF CHEESE AND BUTTER TECHNOLOGY

Cheese-making technology

General principles. **Milk is a biological substance that is particularly susceptible to degradation through the action of microbes and enzymes. This situation mainly arises from its complex composition, where spoilage organisms can find a large variety of nutrients. The high water content and neutral pH also facilitate undesirable changes.**

Cheese-making technology aims to preserve milk so that consumption can be postponed for periods from a few days to several months. The preservation of the product is obtained mainly through lactic acidification and limited dehydration. These operations take place during the two first steps of processing, the setting (or coagulation) and draining phases. For many cheese types, a third phase known as ripening then takes place. This induces changes in the coagulum, separated during draining, caused by complex microbial and enzyme reactions.

In cheese making, control of the preservation process allows these changes to be manipulated in order to obtain a large number of cheese types with distinct physical-chemical and microbial composition and sensory characteristics. The resulting cheeses can be divided into four main categories depending on the level of preservation brought about by acidification (pH) and reduction of the water content (Aw or water activity).

Cheese categories	pH	Aw
Fresh (cottage)	4.3 - 4.5	0.980 - 0.995
Soft	4.5 - 4.8	0.970 - 0.990
Semi-hard	4.8 - 5.2	0.940 - 0.970
Hard	5.0 - 5.2	0.885 - 0.905

Processing stages

Coagulation

Milk clotting coincides with the destabilization of the original micellar state of milk casein. In practice, destabilization is effected by two methods:

- **by enzymic action, using milk-clotting enzymes such as rennet;**
- **by fermentation, using endogenous lactic acid bacteria and/or inoculated lactic starters.**

The mechanisms of the clotting methods are completely different but both lead to the formation of a coagulum called a curd or clot. The physical and rheological properties of the curd depend on the clotting method used (Table 9).

In typical cheese making, the two methods are never used separately but the balance of each is well defined for a particular cheese variety. The different cheese categories can be identified on this basis as follows:

- **fresh cheeses processed mainly with lactic clotting;**
- **semi-hard and hard cheeses processed mainly by enzymic clotting;**
- **soft cheeses processed by balancing the two methods.**

Draining

The fresh coagulum is physically unstable, which leads to a progressive and spontaneous separation of the curd and whey. This development is characterized by segregation of the different components of the milk solids. Most of the water and lactose and a small fraction of the fat and protein accumulate in the whey. Most of the protein and fat are progressively concentrated into the cheese curd according to the method used to drain the whey.

In addition to its clotting effect, the acidification process plays a key role in eliminating the colloidal minerals of the casein micelles. The final solubility level of calcium and phosphorus determines the draining rate of the curd and, in turn, the texture and total solids content of the cheese.

The processing parameters for each type of cheese aim to develop the curd and, at the same time, an acidity profile which induces a specific acidity level and physical-chemical composition. Typical acidity development profiles must be followed during the draining process in order to produce different varieties successfully. This includes the need to know the strength of the lactic acid bacteria and to understand and control the

development of lactic starters.

Ripening

At the end of draining, the composition, volume and shape of the curd are well defined. At this stage, most cheese varieties are placed in ripening rooms. The purpose of this final processing phase is to modify and improve the appearance, composition, texture, flavour and nutritive value of the cheese.

From a chemical standpoint, ripening corresponds to an enzymic development of the curd in which proteolysis and lipolysis are mainly dominant. Casein is hydrolysed during ripening into fractions of low molecular weight: polypeptides, peptides, amino acids and ammonia. The fat is less modified in the majority of cheeses but, conversely, more hydrolysed in some blue types of soft cheeses. As a result, fatty acids, glycerol, aldehydes and ketones are liberated and accumulated in each type of cheese according to a typical profile.

Proteolysis and lipolysis are caused by numerous enzymes of various origin: endogenous milk enzymes, the residual activity of milk clotting enzymes, microbial enzymes produced by moulds and bacteria and yeasts growing into or on the surface of the cheese. This last category is dominant in cheese varieties ripened by these microflora. For cheese without external or internal flora, hydrolysis is much lower.

The optimum pH for the enzymes is generally near neutral (pH 7.0). At the end of draining, the cheese pH, around 4.5 to 5.2 depending on the variety, is too low and unsuitable for optimal development. It is thus necessary in practice to increase the pH, which may be done as follows:

- **for semi-hard and hard cheeses, neutralization occurs as a result of the large amount of minerals remaining in the curd;**
- **for soft cheeses and some semi-hard cheeses, the pH increase is effected by specific microflora that assimilate lactic acid.**

The cheese ripening processes are complicated and specific to each cheese variety. From a practical standpoint, several factors such as regulation of room climate (temperature, humidity, air flow), time and handling (turning and cleaning) are used to obtain a standard product in accordance with the required composition and taste characteristics.

The technology of the main cheese varieties

Fresh (cottage) cheese. **Fresh cheeses are distinguished by various technological characteristics giving each variety its individual character.**

Coagulation

Coagulation during fresh cheese production is mainly acid in character. The cheesemaker reinforces the production of lactic acid first by inoculating the milk with measured amounts of lactic starters (0.5 to 3.0 litres/100 litres) and by adjusting the milk temperature for optimum growth (18 to 27°C). Second, the activity of the milk-clotting enzyme is limited by the use of very low amounts (1 to 5 ml/100 litres) and by setting the temperature as far as possible from the optimum.

Consequently, the progress of coagulation depends closely on acidity development and the subsequent decrease of pH. This development is quite slow. The clotting time varies from 6 to 15 hours and the cutting time increases to around 16 to 48 hours. This long

coagulation time encourages fat creaming when full or standardized milk is processed. In order to avoid this, the use of homogenized or skimmed milk is recommended.

At the end of the coagulation period, the acidity is high (0.65 to 1.00 percent), the pH value is low (pH 4.5 to 4.8) and the curd takes on its particular rheological properties, such as high firmness and brittleness and good whey permeability.

Draining

The ability of acid curd to drain is extremely limited. The final cheese solids content is thus generally less than 30 percent, with a range between 12 and 22 percent.

Spontaneous syneresis remains slow and weak because of the high demineralization of the casein micelles and subsequent low curd elasticity. To obtain reasonable wheying-off times and well drained cheese, it is often necessary in practice to apply some physical treatments to the curd, which must always be carried out carefully because the curd is fragile.

In traditional processing, these treatments consist of cutting, pressing and mixing the curd. The process takes place while moulding the clot in draining bags or hoops and during turning. The total draining period lasts for 24 to 36 hours at room temperature (20 to 30°C). With modern centrifugal processing techniques, removal of whey occurs instantaneously in the separator. This harsher mechanical treatment requires a firmer curd, achieved by increasing the amount of clotting enzyme and the temperature of renneting.

At the end of draining, the cheese is characterized by a low dry-matter content and low pH values and mineralization (0.1 percent calcium and 0.2 percent phosphorus). As a

result, the cheese lacks cohesion and looks like a soft watery paste. For further preservation, the product must be packaged into rigid, airtight cups in order to prevent wheying off and external contamination.

Consumption of fresh cheese generally occurs without ripening immediately after draining. The basic acid taste can be modified by adding a large variety of ingredients, such as cream, salt, sugar, spices or jams. Shelf-life is limited to a few days under refrigerated conditions (0 to 4°C) but can be increased by applying heat treatment or air drying.

Soft cheese. **Soft cheese making is typified by:**

Coagulation

Coagulation takes place using the equal action of milk-clotting enzymes and lactic acid. The average amounts are 15 to 25 ml/100 litres and 1 to 3 litres/100 litres for enzyme and starter respectively. Milk temperature is adjusted for good enzyme and starter activity. The clotting conditions impart specific physical properties into the curd: medium firmness, elasticity and brittleness.

Draining

Soft cheese is drained using mild mechanical treatment in accordance with the rheological behaviour of the clot. These conditions lead to the formation of a cheese of average solids content (45 to 55 percent) and residual mineral content (0.2 to 0.3 percent calcium) and a low pH (4.7 to 4.9). The curd is of average cohesiveness. The size and weight of the cheese is also average.

Ripening

Ripening of soft cheese is fairly rapid (two to eight weeks) depending on the water content and the occurrence of microflora with high enzymic activity growing on the surface or inside the cheese. On the basis of the dominant type of ripening organism, three soft cheese categories may be distinguished:

- **soft cheeses with surface moulds: *Penicillium camemberti*;**
- **soft cheeses with surface bacterial flora: *Brevibacterium linens*;**
- **soft cheeses with internal moulds: *Penicillium roqueforti*.**

Semi-hard and hard cheese. **The processing of these cheese classes is defined by the following characteristics:**

Coagulation

The main enzyme coagulation action is obtained by using high concentrations of clotting enzymes (20 to 40 ml/100 litres) and by adjusting the temperature to a level which is moderate for enzyme activity (32 to 40°C). For the same reason, lactic acid development remains very limited through the use of low initial amounts of mesophilic and/or thermophilic bacteria (0.5 to 1 litre/100 litres).

Under these conditions, clotting time is short (10 to 30 minutes). The curd possesses the typical properties of an enzymic gel: good elasticity, low brittleness and high syneresis ability, all of which are directly induced by high casein mineralization.

Draining

Drainage of the curd is fast and thorough. The high solids content (45 to 70 percent), is reached by applying physical treatments such as cutting, stirring, washing, cooking and pressing. These actions are improved by moderate parallel acid development of the curd. This development is aimed at obtaining high curd mineralization (1.2 to 1.8 percent calcium) and a large cheese. The pH value at the end of draining ranges from 5.0 to 5.2.

Draining takes from 20 to 48 hours, with the greater part of the whey running off during the first two hours. The final pressing is carried out mainly to compact the curd grains rather than to induce further draining.

Ripening

The process of cheese ripening is conditioned by internal neutralization determined mainly by the interaction between lactic acid and calcium. In some cheeses, complementary neutralization takes place through development of microflora on the surface, as in soft cheeses.

These interactions induce progressive neutralization and subsequent protein and fat breakdown in the cheese. Among the various sources of enzymes involved in ripening, the clotting proteases and those of microbial origin are most involved. For some hard cheese types (Gruyère and Emmenthal), specific propionic fermentation develops during the second part of the ripening period, providing the typical holes and flavour.

The average ripening time is three weeks to six months under factory conditions and can extend to 6 to 12 months for traditional production according to dry- matter content. The temperature of the ripening rooms is normally between 12 and 14°C. When

propionic fermentation is required, the temperature is increased to about 20°C during the latter part of ripening.

During the ripening period, it is necessary to cure the cheese surface in order to regulate growth of certain microbial flora or to inhibit adverse growth on products with dry coats or crusts.

Cheeses made from whey. **Whey generally contains significant amounts of whey proteins (0.75 to 0.95 percent), which consist largely of lactalbumin and lactoglobulin (Webb, Johnson and Alford, 1974). These proteins coagulate when heat is applied (Lyster, 1979) and are easily collected after precipitation. Heat denaturation begins when the temperature is close to 65°C and increases with the time-temperature combination used during heating.**

In practice, these properties are exploited to produce the specific dairy products known as "whey cheeses", which are traditionally manufactured largely in the countries around the Mediterranean (Pernodet, 1979; Ramet, 1985c; Kandarakis, 1986). These products are not genuine cheeses, because they are not obtained directly from the coagulation of milk.

Processing consists of selecting whey rich in soluble proteins and, preferably, drained from hard cheeses made from raw or thermized milk. The whey is slowly heated for 20 to 45 minutes to between 78 and 95°C and held at that temperature for a further 15 to 30 minutes. The first clotted particles appear at around 78 to 80°C, depending on acidity and whey protein concentration. The clusters of coagulated proteins gather at the surface of the whey and can be easily collected using simple techniques such as filtration through cloth or skimming with a ladle.

The degree of heating influences the quality of the cheese. Above 88°C, the texture tends to become drier, harder and more granular. A cooked flavour makes the cheese less acceptable. Below these temperatures, the clusters are small, crumbly and difficult to gather; the precipitate is watery and drains slowly. Cheese yields are variable and closely dependent on the richness of the whey and the water content of the final product. For example, the yield from cow's milk cheese whey can reach 3.5 kg/100 kg. The solids content of whey cheese is around 20 to 25 percent; the percentage of fat in dry matter is generally between 11 and 45 percent.

The keeping quality of the product is poor because of the high water content and reduced acidity (pH 5.5 to 6.2). The cheese can be eaten like other cheese or used in cooking and pastry.

Numerous alternatives to the above-mentioned process are used. These processes are aimed at improving recovery of whey proteins and increasing the total solids of the cheese to 40 to 50 percent, as with ricotta or *brucciu*. The best method consists of adding from 20 to 30 percent whole milk to the whey or increasing the acidity to pH 4.6 to 5.8 (Kandarakis, 1986). Acid development may be supplemented with organic acids such as acetic, citric, lactic or tartaric, with mineral acids like phosphoric acid or by using acid whey. The addition of salts (0.1 to 0.5 percent calcium and/or sodium chloride) is sometimes used for the same purpose.

The most modern processes involve more sophisticated techniques such as ultrafiltration to concentrate whey proteins prior to heating or centrifugation to enhance separation of precipitates.

Whey cheese is generally accepted by local consumers because of its typical taste and

smooth texture. Nutritional value is high because of the richness of whey proteins in essential amino acids, mainly cystine and methionine (Porter, 1978).

Summary of butter-making technology

The fat globule. **The fat in cow's milk is emulsified as fat globules 3 to 5 micrometres in diameter. The fat globules have a heterogenous structure composed of three parts: an external membrane, a central core of triglycerides with high melting points and an intermediate stratum of triglycerides with low melting points. The stability of the fat emulsion is dependent on the integrity of the globular structure.**

Butter making consists of destabilizing the emulsion in order to concentrate the fat content from 3.5 to 4.5 percent in milk to 82 percent in butter. This transformation proceeds through several mechanical and chemical stages.

The phases of butter making. **The first step of butter processing is to separate the milk to obtain cream with a fat content about ten times higher than milk. The process can be carried out by natural creaming of milk in the traditional way or by modern centrifugal techniques.**

Sometimes, when the acidity is in excess of 0.2 percent, it is necessary to neutralize the cream in order to avoid coagulation during heating and development of disagreeable flavours in the butter. Neutralization is carried out either by dilution with water and further separation or chemically using sodium hydroxide.

Heat treatment of the cream is recommended to eliminate the bacteria and enzymes that could cause quality problems and spoilage. For this reason, the cream is heat treated at a temperature of 90 to 95°C for between 30 seconds and two minutes. Heating takes

place in containers (vats, cauldrons, etc.) or in tubular or plate exchangers. Optional de-gassing may be used to remove disagreeable flavours which may be dissolved in the water or fat. After heating, the cream is cooled to between 8 and 14°C for ripening. Ripening, or ageing, is used to lower the pH slightly, to develop flavour and to regulate fat crystallization.

Biological ripening is effected by adding a lactic starter for 10 to 16 hours at 8 to 14°C. The cream acidity required for traditional churning methods is 0.40 to 0.45 percent but only 0.20 to 0.35 percent for continuous butter making. During ripening, lactic acid bacteria also produce flavouring molecules such as diacetyl, which are important in building up the typical cooked or hazelnut flavour.

Physical ripening is carried out to regulate the proportion of solid and liquid fat. At low temperatures all the fat is crystalline, leading to long churning times and very hard butter texture. If the temperature is too high, all the fat melts and the butter will be very soft, resulting in considerable fat losses in the buttermilk. Another important factor in physical ripening is control of the cream cooling rate. If this is too slow, large fat crystals will form, leading to a fractured, sandy texture in the butter. If the cooling rate is too fast, the crystals are small and not detectable in the mouth. As a result, the texture of the butter is significantly improved.

The final phase of butter making consists of breaking a limited number of fat globules in order to expel a small amount of liquid fat that will ensure a continuous bond with adjacent globules. When this bonding takes place, grains of butter appear. In order to facilitate this development, the fat globules have to come together during churning. This is brought about by the formation of foam as churning of the cream begins. As churning continues, the bubbles get smaller, making the foam more compact and so

applying pressure on the fat globules. As the bubbles become increasingly dense, more liquid fat is squeezed out and the foam becomes so unstable it collapses. The discharge of the liquid fat is caused by the impact of globules against each other and against the surface of the churn. Immediately the butter particles appear, the foam collapses and buttermilk separates from the butter.

When the butter particles become large enough for separation, the buttermilk is run off and churning, or working, continues. If the butter is intended for storage, it is washed several times with water that is bacterially and chemically pure. After churning and washing, working the butter in the churn ensures dispersion of any residual buttermilk droplets into the butter. Churning adjusts the water content of the butter to the legal maximum of 16 percent, when such regulations exist.

After working, the butter is removed from the churn and packed. Packaging materials and containers must provide effective protection against microbial contamination and must be opaque, as light increases fat oxidation. The keeping quality of the product depends on the residual content of microbes and enzymes and on the storage temperature. For storage over several months or years, deep freezing to -20 to -35°C is required. In traditional production methods, the butter is melted and boiled to destroy spoilage organisms and enzymes and kept for several months in cans or glass or earthenware jars.

Camel milk and cheese making

In traditional pastoral systems, camel milk is mainly used for feeding calves and for human consumption. Two quarters of the udder are usually selected for milking and segregated with ropes, while the calf suckles the other two quarters (Ramet, 1987; Ramet, 1989a; Ramet, 1994a).

Milk for human consumption is usually drunk immediately after milking. It can also be consumed as fermented milk made by natural lactic souring over several hours in a skin or clay container. The fermented milk may sometimes be separated by vigorous shaking; the acid skimmed milk is drunk and the butter used for cooking or cosmetic or medicinal purposes (Yagil, 1982).

The processing of camel milk into cheese is said to be difficult, even impossible (Dickson, 1951; Gast, Maubois and Adda,1969; Yagil, 1982; Wilson, 1984). It is surprising that although the majority of pastoral systems have produced at least one type of cheese, no traditional methods exist for making cheese from camel milk. This might be explained by local cultures which allow the consumption of camel milk only as drink and exclude the possibility of trade. It is also possible that the highly perishable nature of cheese in hot desert climates has not been conducive to creating trade between isolated communities.

In addition to these cultural considerations, it appears that camel milk is technically more difficult to process than milk from other domestic dairy animals. A bibliographic review indicates that in the Ahaggar region and the Sinai peninsula only a few rare cheeses are manufactured by acidic separation and heating of milk proteins (Gast, Maubois and Adda, 1969; Yagil, 1982). These products seem to have the characteristics

of perishable fresh cheese with a high moisture content. Shelf-life may be increased to several months by air and sun drying (Abeiderrahmane, 1994). It is noted that these cheese types do not come under the standard definition of cheese which results from the simultaneous action of a milk clotting enzyme and lactic souring (Ramet, 1985b).

COAGULATION

Enzyme coagulation

Action of clotting enzymes on camel milk.**Most attempts to make cheese from camel milk have revealed major difficulties in getting the milk to coagulate. Initial field attempts increased the rennet concentration compared with that usually used for clotting cow's milk by 50 to 100 times (Gast, Maubois and Adda, 1969; Wilson, 1984). More recent attempts confirm that the rennet coagulation of camel milk is two to four times slower than for cow's milk treated under the same conditions (Ramet, 1985a; Farah and Bachmann, 1987; Ramet, 1987; Mohamed and Larsson-Raznikiewicz, 1990).**

This specific behaviour has been observed with most of the clotting enzymes used for coagulation. Significant differences in the inhibition of clotting activity related to the origin of the enzyme have been noted, however. Several observations (Ramet, 1985a; Ramet, 1990) have shown that bovine pepsin coagulates camel milk well. Calf rennet and the clotting enzyme extracted from *Mucor miehei*have an effect similar to but lower than bovine pepsin. Chymosins of genetic origin and proteases of *Endothia parasitica* ave the lowest effect (Figure 2).

Milk clotting trials made under similar conditions, using either milk reconstituted from

low-heat powdered milk (pH 6.65) or fresh raw camel milk (pH 6.55), have demonstrated a noticeable improvement in clotting camel milk compared with cow's milk when calf rennet, *Mucor miehei*and *Endothia parasitica*proteases and genetic chymosin were used. With bovine pepsin, the clotting time was five times shorter in camel milk (Table 10). This unique behaviour of pepsin could be explained by its higher affinity for camel milk and its limited activity at a near-neutral pH.

These different affinities, which depend on enzyme source, could be partly explained by the incidence of environmental factors (pH, temperature, ionic strength, etc.) regulating enzyme activity. The main origin of the disparity in the clotting effect of the different milk-clotting enzymes could more probably be the presence in camel milk of specific protease inhibitors and/or a particular casein micelle structure limiting access of the protease to the kappa casein substrate. These hypotheses are yet to be confirmed.

More generally, it must be stated that some nomads in the Sahara and Sinai seem to be able to make cheese using parts of the stomach of the desert rabbit as a coagulating agent (Gast, Maubois and Adda, 1969; Yagil, 1982). This stomach contains pepsin (Lebas, 1991). More recent work carried out in Egypt (El-Abassy, 1987; El-Batawy, Amer and Ibrahim, 1987) shows that the pepsin produced from the stomach of the adult camel is just as good in terms of activity and stability. However, this work did not deal with the general ability of the enzyme for cheese making. It appears that using the stomach of young camels for making camel cheese has never been investigated or tried, which is strange. Moreover, no work has mentioned the actual enzyme composition of the camel calf stomach.

A further distinguishing feature of the *Mucor miehei* nzyme when used in weak concentration in camel milk is to cause partial inhibition, as shown by the non-linear

relationship between the clotting time and the inverse of enzyme concentration (Figure 2). This phenomenon, previously observed in raw cow's milk, probably originates from the enzyme reacting with the whey proteins. As a consequence, in practice the enzyme quantity has to be slightly increased. The inhibitory effect disappears when the milk is heat treated under high time-temperature pasteurization conditions (Ramet, 1985a).

Curd formation and rheological properties. **any observations of making cheese from camel milk point to the difficulty in measuring the early stages of coagulation. An empirical appraisal of the physical properties of milk during the liquid to gel transition phase is not easy because of the persistence of a diffuse, curd-like pseudo-gel. Further build up of the coagulum is slow and weak (Ramet, 1985a; Farah and Bachmann, 1977; Ramet, 1991; Ramet, 1994a). The gel texture is characterized by low elasticity and high fragility. Moreover, the fragility of the curd is increased where acid fermentation occurs (Ramet, 1987; Ramet, 1994a). On a practical note, this rheological development indicates the need to increase the speed of coagulation in order to avoid making the curd too weak to withstand the mechanical action used in draining.**

This unique rheological behaviour has been traced by empirical methods (Gast, Maubois and Adda, 1969; Ramet, 1985a; Ramet, 1987; Mohamed and Larsson-Raznikiewicz, 1990; Ramet, 1994a) and confirmed and quantified by instrumental methods. Figures 3 and 4 show examples of measurements made by gelograph and turbidimeter (Farah and Bachmann, 1987; Ramet, 1990; Bayoumi, 1990).

The relationship between milk composition and clotting ability.Influence of casein composition. **he limited ability of camel milk to be coagulated by enzymes is probably largely due to the composition of the casein micelles. Some recent research has shown that the kappa casein, representing the micellar fraction which reacts with the clotting**

enzymes, has a different electro-potential from cow's milk, which causes lower electrophoretic mobility (Farah and Farah-Riesen, 1985; Jardali, 1988; Mohamed and Larsson-Raznikiewicz, 1990; Farah, 1993; Larsson-Raznikiewicz, 1994.)

This unusual behaviour indicates a very specific casein micelle composition characterized by a low proportion of kappa casein. Relevant data are listed in Table 3, which indicates that the average content of kappa casein in camel milk from various sources rises to only about 5 percent of total casein, compared with 13.6 percent in cow's milk (Jardali, 1994). Camel milk casein also differs in terms of micellar size (Table 4). Instrument measurements showed that the mean diameter ranges from 280 to 325 micrometres, about double the 160 micrometres in cow's milk (Farah and Bachmann, 1987; Jardali, 1988; Farah and Ruegg, 1989; Jardali and Ramet, 1991).

It is important to emphasize that seasonal variations in the composition and size of casein micelles have also been found in cow's milk. These are caused by the variable effect of environmental factors such as temperature and feed availability. For example, a noticeable variation in the diameter of the micelles from 150 to 250 nm was observed in bulk milk collected in the eastern part of France. During the hot season, the micelles are larger and lower in kappa casein. The same milk had a reduced ability to coagulate compared with winter milk. The clotting time with rennet was longer and the firmness of the curd significantly reduced. In the cold season, on the other hand, the micelles were richer in kappa casein, coagulated faster and produced stronger curd (Ekstrand, Larsson-Raznikiewicz and Perlmann, 1980; Niki and Arima, 1984; Scher, 1988).

Adding rennet to camel milk causes a proteolytic reaction which can be traced through the development of the quantity of non-protein nitrogen. The trend of the curves shows that hydrolysis is similar in camel milk and cow's milk, although the percentage of

kappa casein is quite different (Farah and Bachmann, 1987; Mehaia, 1987).

It appears that the secondary reaction of the clotting process in camel milk, which corresponds to the aggregation of casein micelles, occurs in a definite sequence. It has been observed by electronic microscopy that in cow's milk a homogenous network of micelles existed after a time corresponding to 80 percent of the visual clotting time. In camel milk, the aggregation of micelles occurs later and the network is softer and less dense (Farah and Bachmann, 1987). It seems that the reduced ability of micelles to polymerize is the result of the weak capacity of the substrate to link calcium bonds with particles. The large-sized micelles are known to be lower in calcium than the smaller ones (Scher, 1988). Measurements made elsewhere during the hot season showed that the content of colloidal calcium bound to the micelles in camel milk was much lower (35 percent of the total calcium) than in cow's milk (65 percent) and that the total calcium content was also much reduced by water restriction (Yagil and Etzion, 1980; Yagil, 1994).

The major role of calcium in the coagulation process is corroborated by the fact that controlled enrichment of camel milk with ionic calcium drastically reduces clotting time and reinforces the gel strength more than in cow's milk under similar conditions (Ramet, 1985a; Ramet, 1987; Farah and Bachmann, 1987; Jardali, 1994; Ould Eleya and Ramet, 1994).

Influence of total solids.**It is known that the rheological properties of curd also depend closely on the total solids in the milk and are improved as total solids are increased. The components of the dry matter behave differently during clot formation. The casein content has the major role: the higher it is, the stronger the formation of the micelle network. Fat is not active in gel formation. Fat globules are caught in the casein matrix,**

where they decrease clot rigidity. At a similar fat percentage, the curd is much weaker in the presence of small fat globules than with larger ones. The soluble substances do not act directly on gel formation; they only modify the viscosity of the whey located in the interspaces of the curd.

Analyses show that the dry-matter content of camel milk varies according to the origin of the milk (Table 2). Similar variations exist in the fat and protein contents. Generally, however, the fact that the amounts of these components are lower than in cowmilk explains the lower rheological quality of camel milk curd. Such adverse effects occur most when animals have restricted access to water. It has been observed, for example, that total solids can fall from 14.3 to 8.8 percent, protein from 4.6 to 2.5 percent and fat from 1.3 to 1.1 percent (Yagil and Etzion, 1980; Yagil, 1994).

A third cause of weaker curd rigidity in camel milk is the small size of the fat globules, which are between 1.2 and 4.2 micrometres instead of the 1 to 10 micrometres in cow's milk (Dong Wei, 1980; Knoess *et al.* 1986; Farah, 1993).

Acid coagulation

Milk composition and acid fermentation ability. **The acid coagulation of camel milk is governed by lactic acid bacteria which originate either from the raw milk or from the external inoculation of lactic starters (Ramet, 1985a). The ability of camel milk to acidify is, in turn, dependent on several compositional factors which interfere with bacterial growth.**

Milk may be considered a medium favourable for microbial growth with a near neutral pH, a high water activity and a large variety of nutritive substances facilitating the

proliferation of cells including lactic acid bacteria. Lactose is the nutrient of prime importance. Although its content in camel milk may vary greatly depending on feeding and watering conditions (Yagil and Etzion, 1980; Yagil, 1994), it appears that lactose availability is always satisfactory, even in cases of strong acidity. There are no studies of nitrogen nutrition that assess the precise requirements of lactic bacteria in relation to the specific composition of camel milk.

On the other hand, a bibliographic review indicates that raw camel milk contains several antimicrobial agents that can limit microbial growth to a higher degree than in milk from other domestic animals. Significantly high levels of lysozyme (Barbour *et al*, 1984; El Sayed *et al*, 1992; Farah, 1993) and vitamin C (Kon and Cowie, 1972; Knoess, 1979; Yagil, 1982; Yagil, Saran and Etzion, 1984) are reported. More recently, the antimicrobial activity of other natural proteins such as lactoferrin, lactoperoxydase and immunoglobulins was studied (Monnom *et al.* 1989; IDF, 1991; El Sayed *et al.* 1992; El Agamy,1994). Each of these antimicrobial agents possesses a selective spectrum of activity against specific strains of bacteria and viruses.

As a major consequence, when fresh raw milk is allowed to sour, a bacteriostatic period is observed for the first few hours after milking. This lag phase is greater in camel milk (four to six hours) than in cow's milk (two to three hours). Acid development rates are slower throughout the incubation period (Ramet, 1985b; Ramet, 1987; Gnan *et al.* 1994a). After camel milk has been heat-treated using thermizing or high pasteurization conditions, partial inhibition persists because the antimicrobial factors could be rather more heat-resistant than in cow's milk (Ramet, 1994a; El Agamy, 1994). Another reason for the reduced acid production rate appears to be related to the higher buffering capacity of camel milk compared with cow's milk (Rao, Gupta and Dastur, 1970; Ramet, 1985b; Ramet, 1987; Farah and Bachmann, 1987).

Formation and rheological properties of lactic gels. **hroughout the course of acidification of cow's milk, progressive neutralization of the electric charges of the casein micelles occurs, leading to the emergence of the curd. The coagulation point occurs earlier when the acidity and temperature are high (Veisseyre, 1975; Ramet, 1985a). In camel milk, it is difficult to detect a similar development because the formation of the clot is slow and unstructured and resembles a flock rather than a precipitate (Ramet, 1985b; Ramet, 1987; Farah and Bachmann, 1987).**

DRAINING ABILITY

Curd properties and syneresis

The ability of curds to drain is directly dependent on their rheological properties, which develop throughout the hardening phase, taking into account the development of firmness and elasticity.

The extreme weakness of camel milk curds causes the destruction of the casein network if physical treatment applied at cutting and moulding is not done carefully and slowly. If these conditions are not observed, a significant portion of the dry matter of the milk is not retained in the cheese but lost in the whey. Recovery is then limited to about 30 percent, whereas it increases to about 50 percent for cow's milk and 68 percent for sheep's milk under similar manufacturing conditions (Ramet, 1990).

The draining of curd made from camel milk is characterized by rapid syneresis compared with cow's milk. Figure 7 shows the large difference during wheying off measured in a curd obtained chiefly by acid coagulation (Ramet, 1987). This

development appears to be a consequence of the low water retention capacity of the gel because of its rather limited casein content. Another factor is that the hydration of camel milk casein micelles is reduced by the low kappa fraction, which is very hydrophilic, and by the restricted surface area relative to its high volume (Jardali, 1988; Scher, 1988; Jardali, 1994). It should be noted that similar significant relationships have been observed when seasonal variations in the composition of cow casein micelles have been accurately measured. In the hot season, micelles are larger but lower in kappa casein and the resulting curd has a weaker water-retention capacity than in the cold season (Scher, 1988).

The fact that the acidification rate is slower in camel milk appears to have no adverse effect on wheying off. It must be stressed, however, that under these conditions the protective effect of acidity in preventing the spread of spoilage organisms is delayed. It is thus necessary to make the cheese under especially hygienic conditions.

Whey composition

The composition of camel milk whey is characterized by higher total solids than cow's milk, at 7.0 and 6.5 percent, respectively, whereas the dry-matter content is often lower in camel milk whey (Ramet, 1987; Ramet and Kamoun, 1988; Kamoun and Bergaoui, 1989; Ramet, 1994a). It has been emphasized that fat content is particularly high, reaching three to four times the value measured in whey from cheese made under similar conditions from cow's milk - 0.3 and 1.3 percent, respectively. This concentration is equivalent to more than 60 percent of the content of the milk (Ramet, 1989b; Mohamed, 1990; Ramet, 1994a). The small size of fat globules and the fragility of the casein micelle network are the cause of these losses.

The whey from camel milk cheese is identified by its white colour, compared with the greenish whey from cow's milk cheese (Ramet, 1989b; Ramet et Kamoun, 1988; Mohamed and Larsson-Raznikiewicz, 1990; Ramet, 1994a). This property of camel whey is probably the result of a concentration of small particles (proteins, fat globules) which, through complex diffraction and refraction phenomena, cause the white colour. Another reason could be the low concentration of riboflavin in camel milk (Webb, Johnson and Alford, 1974; Farah, 1993).

RIPENING

Little information is available on the ripening of cheese made from camel milk. What is available is based on experimental production carried out using small quantities of milk. The first commercial production started recently in Mauritania in a new, purpose-built camel cheese-making facility (Ramet, 1994b). Trends may thus be observed but final conclusions cannot yet be made.

Results from sources in Tunisia (Ramet, 1987), Saudi Arabia (Ramet, 1990) and Mauritania (Ramet, 1994b) show that the taste of fresh camel cheese is highly satisfactory. The smooth texture and sharp taste of the curd were well liked by a tasting panel. Similar results were observed by most of the panellists for soft cheese with a total solids content of 35 to 45 percent at the end of draining. However, some judges trained in the sensory evaluation of soft cheese made from cow's milk have noticed a rougher texture in camel cheese. The somewhat chalky structure is probably a result of the reduced fat content of the cheese because of high fat losses in the whey and the weak water-binding capacity of camel milk curd. The sensory profile of soft camel

cheese is very similar to that of low-fat soft cheese made from cow's milk. A similar crumbly, granular texture has been also found in semi-hard and hard cheese (Ramet and Kamoun, 1988; Mohamed and Larsson-Raznikiewicz, 1990; Ramet, 1994a). The last observation confirms that the cheese becomes less smooth when the fat and water contents decrease.

Another defect is that greasy, sticky cheese curd has sometimes been noted. The cheese tends to adhere quite strongly to the tongue and palate while it is being chewed. No explanation of this is known but it seems that some properties of the camel cheese fat, such as the high level of short-chain fatty acids and their significantly high melting point (Abu-Leiha, 1987; Abu-Leiha, 1989; Farah and Ruegg, 1991; Mehaia, 1994) may be related to the phenomenon.

Temporary bitterness has been noted in some soft and semi-hard cheeses (Ramet, 1987; Ramet and Kamoun, 1988; Ramet, 1994a). The defect is detected mainly after the cheese has been swallowed. This perception of bitterness is delayed because the receptors sensitive to bitter molecules are located at the back of the tongue.

The probable origin of the bitterness in camel milk cheese has not been clearly determined. It is known that bitterness in dairy products may be caused by factors such as alkalis of ingested plants, salts of external origin - mainly calcium and magnesium chlorides - and carbonates or bitter peptides generated by casein hydrolysis. The most likely cause is those proteolytic residues which accumulate when the pH of the cheese is low and a high residual proteolytic activity from the clotting enzymes remains in the curd. The fact that it is necessary to overdose the clotting enzyme to speed up coagulation of camel milk indicates the last possibility as the origin of the bitterness.

PRODUCTS OBTAINED FROM WHEY

Whey cheese

Producing whey cheese by coagulating the soluble proteins in camel milk whey is more difficult than with cow's milk whey, at least when traditional methods are used. When camel milk whey is heated, aggregates of denatured proteins begin to form at temperatures between 72 and 80°C (Ramet, 1987; Mohamed and Larsson-Raznikiewicz, 1990; Ramet, 1994a). However, the particles remain very small and isolated and do not come together during further heating as in cow's milk. When left at ambient temperature for ten to 16 hours, three distinct phases occur: an upper floating layer composed of water, proteins and fat; an intermediate layer made up of clear whey; and a weak white precipitate at the bottom. The separation of the upper part by traditional simple filtration is ineffective. Alternatives to this process, such as acidification with lactic and citric acids, addition of calcium and sodium chlorides or addition of 30 percent of acid camel milk, do not improve collection of the particles (Ramet, 1987; Ramet, 1990). The only way to separate is to use a centrifuge, which allows a watery concentrate to be recovered with about 16 to 22 percent total solids (Ramet, 1990).

The unique behaviour of camel milk whey compared with cow's milk whey could be explained by differences in the composition of the soluble whey proteins and their higher heat stability (see The main constituents on p. 3). It has also been noted that when cow's milk is strongly heated, a reaction occurs between beta-lactoglobulin and kappa casein that makes the formation of large aggregates easier (Zittle *et al.* 1962). Absence in camel milk of a protein similar to beta-lactoglobulin and low kappa casein

content could cause this different behaviour. Finally, it is possible that the high amount of fat in camel milk whey could have some adverse effect on the surface properties of the whey protein particles, leading to their dispersion.

Whey butter

Given the very high fat content of camel milk whey, the question arises whether it is possible to make butter from it. A review of the literature indicates that making butter from camel milk whey has been controversial for a long time. Many nomads do not produce butter from pure fresh camel milk (Dickson, 1951; Wilson, 1984), whereas some authors report that butter is produced under good management conditions (Yagil, 1982). Research has confirmed that butter making from camel milk whey is feasible but more difficult than with cow's milk whey (Farah, Streiff and Bachmann, 1989; Ramet, 1990).

The difficulties seem to stem from the properties of the fat globules, which are generally small with a thick membrane (see The main constituents on p. 3). For these reasons, the mechanical resistance of the fat globules is probably strengthened, which results in a long churning time of about five hours when milk is directly processed without prior centrifugal concentration of the fat (Ramet, 1990). If the agitation of whey is carried out after increasing the acidity to pH 5.0, churning time is reduced to one to two hours.

The concentration of the fat emulsion into cream by natural creaming or by centrifugation was found less easy than for cow's milk because of the small size of the globules. To obtain 20 to 30 percent cream fat, it is necessary to double centrifugation. This leads to a significant reduction in churning time, which promotes the occurrence

of butter grains. The time falls to between five and 45 minutes, depending on temperature, fat content and cream acidity (Farah, Streiff and Bachmann, 1989; Ramet, 1990). Acidifying the cream makes churning faster but lowers fat recovery in butter (Figure 8).

A feature of the composition of camel milk fat is its low short-chain fatty acid content and high proportion of palmitic and stearic acids. This results in high melting and solidification points compared with cow's milk: 41.4 to 41.9°C and 30.5°C for camel milk and 28 to 32°C and 22.8°C for cow's milk. It was shown earlier (see Summary of butter-making technology on p. 8) that temperature is important to balance the physical state of the fat. The major role of temperature is confirmed by the fact that formation of butter grains does not occur at 10 to 12°C, which is the usual churning temperature for cow's milk cream, and that over 36°C the butter yield begins to fall. The best conditions for making butter are 25°C for a 22.5 percent fat cream with a churning time of 11 minutes (Farah, Streiff and Bachmann, 1989).

The sensory profile of butter made from camel milk is conditioned by its very white colour (Farah, Streiff and Bachmann, 1989; Ramet, 1990), which probably results from a high amount of non-fat components such as proteins linked to the fat globules, and considerable retention of buttermilk by capillary action (Ramet, 1990). The butter is greasy and sticky when eaten or cut with a knife (Farah, Streiff and Bachmann, 1989; Ramet, 1990). The flavour is neutral and unlike butter made from cow's milk.

The foregoing remarks on butter processing are only hypotheses as to the feasibility of making butter from camel milk whey. It is obvious that the fat in whey is more adulterated than in milk or cream as a consequence of the physical and chemical processes applied during the different stages of cheese making. It appears that

churning times and fat losses in buttermilk are more important than for fresh cream. For the same reason, the taste and keeping qualities of camel whey butter would also be less satisfactory.

Drinks made from whey

Trials have shown that camel milk whey may be used to make acidified drinks. These drinks have an excellent nutritive value because of the presence of essential amino acids, lactose, lactic acid, vitamins and minerals. The taste properties of whey are well known: it is sweet or slightly acid depending on the level of acidity. These dominant flavours can be masked if a milky taste is to be avoided by adding concentrated juices from acid fruits. Because of the opaque colour of whey and the possible presence of a whey protein precipitate, it is better to use cloudy juices that contain pulp, such as citrus fruits. The low pH of these juices gives the whey a characteristic refreshing taste; the additional acidity is protection against development of most spoilage organisms. Consumption of the product should be within two to three days. Additional preservation by pasteurization is necessary for longer-term storage.

Ways of improving cheese made from camel milk

SELECTION OF HIGH-GRADE MILK

Milk used for making good cheese must meet certain critical physical, chemical and microbial standards. These standards, which should be rigorously imposed when the milk is intended for human consumption, have been widely reviewed in specialized publications. More detailed information on quality control, milk collection and keeping methods may be obtained from the following publications: Ramet, 1985c; Scott, 1986; Robinson, 1990a; Weber, 1985; Lambert, 1988; IDF, 1990. The main points are covered in the following sections.

Segregation of abnormal milk

Milk must be obtained only from healthy animals. Milk from sick animals may contain bacteria harmful to consumers. If the animals have been treated with antibiotics, their milk may include residues whose residual action might inhibit development of lactic acid starters when the milk is processed into fermented dairy products such as cheese.

Colostrum milks, secreted at the beginning of lactation, are not suitable for cheese making because of low casein and high salt levels. They should be avoided for one to two weeks after calving. Camel milk produced by animals under serious water shortage conditions contains abnormally low milk solids and its cheese processing ability is poor. It should be discarded or mixed with milk from other camels that is richer in dry matter or with other milk that is better adapted to cheese making.

Microbial quality

The potential vectors of milk contamination are numerous and of various origins. They include: dirty animals, soiled udders, contaminated dairy utensils and cloths and dirty

hands of milkers. Strict observance of accepted cleaning and disinfecting procedures is vital to ensure good quality milk and dairy products.

The following rules should be followed:

- **The udder skin is often heavily soiled with manure and dirt. It is necessary to clean it carefully with a single-use paper towel or a cloth towel moistened in lukewarm disinfectant. The udder should then be wiped dry.**
- **The first milk drawn from each udder quarter is always charged with microbes. It should be collected separately and not mixed with the milk obtained later.**
- **Microbial contamination may be caused by inadequately trained milkers. To get good quality milk, milkers should:**

  - be healthy people without open wounds, particularly on the hands;

  - wash and dry the hands before milking;

  - not handle utensils with dirty hands;

  - thoroughly clean and disinfect each utensil in contact with milk;

  - work in a clean place or room without dust, insects, manure or stagnant water;

  - cool milk rapidly to 0 to 4°C if processing or consumption does not occur within five to eight hours of milking. (Even at these low temperatures, psychrotrophic bacteria may grow. The total raw milk holding period should not last more than 24 to 48 hours, depending on the level of contamination.)

Surfaces that are in contact with milk and dairy products must be efficiently cleaned and disinfected. The average generation time of microorganisms is around 20 to 30 minutes under optimal growth conditions (temperature: 25 to 35°C; pH: 6.65; water activity (Aw): more than 85 percent).

Ideally, the following manual cleaning and disinfecting methods should be followed:

- **rinse dirty surfaces with cold or tepid water, then soak the utensils if cleaning can not be done immediately;**
- **prepare a non-abrasive alkaline detergent solution with a concentration of 0.5 to 1 percent at a temperature of 40 to 45°C;**
- **soak dirty utensils and cover all surfaces for five to ten minutes;**
- **brush vigorously with a nylon brush to remove all debris and stains;**
- **rinse with drinking-water to remove all traces of the detergent;**
- **air-dry and store utensils away from moisture, dust and insects;**
- **before re-use, disinfect utensils by soaking in chlorine solution at a concentration of 250 mg/litre at 35 to 40°C for ten to 20 minutes;**
- **rinse again with potable water to eliminate the chlorine residues.**
- **It should be noted that:**
- **most alkaline detergents and disinfectants are abrasive to aluminium and its alloys at room temperature and cause blackening and corrosion of the metal; the given soaking times must not be exceeded;**
- **stainless steel is resistant to the action of detergents even at high temperature but, unfortunately, it is attacked by chlorine disinfectants at over 45°C; the concentration of chlorine and its germicidal efficiency fall with time because of loss of gaseous chlorine;**
- **use of low detergent and disinfectant concentrations and short soaking time may**

cause emergence of microbial strains resistant to the active agents in detergent and disinfectant solutions;

- **use of soft water for rinsing is recommended;**
- **the concentration of chlorine in industrial disinfectant preparations varies from 12 to 50 chlorometric degrees (1 chlorometric degree = 3.17 g/litre).**

MILK PREPARATION

Heat treatment

Raw milk always contains microorganisms whose importance and variety depend on the health of the animal, hygiene conditions during milking, the milk collecting system and time-temperature conditions during storage (Ramet, 1985b; IDF, 1990). Among the microbe population, some categories are more dangerous because they may transmit diseases to humans (pathogenic germs) or cause defects in the final product (gas-forming, proteolytic and lipolytic cells). Depending on the extent of microbial growth and subsequent cell concentration, such contamination may cause problems during processing or sensory defects in the finished product (blowing, poor texture, bitterness and rancidity) or lead to the destruction of the product.

Raw milk contains varying quantities of lactic acid bacteria suitable for processing cheese. These bacteria produce the lactic acid required for further draining and acid protection of the curd. This natural acidification of milk is, however, variable in speed and intensity because it depends on factors that are not related to time. As a result, the processing and final quality of the product would not be regular. Heat treatment of milk balances out these unknowns but requires the addition of lactic starters prior to the

coagulation phase. For hygiene and technical reasons, heat treatment of camel milk prior to processing into cheese is strongly recommended.

On the basis of cheese-making trials carried out under various conditions with milk from different origins (Ramet, 1987; Ramet, 1990; Ramet, 1994a; Ramet, 1995), it appears that thermizing (62°C for one minute) or pasteurizing (72°C for one minute) are best for microbial stabilization of camel milk and for preventing occasional curd blowing (Table 11). The results show that milk clotting and draining ability are progressively reduced if higher heat treatment conditions are used.

The main features noted during coagulation were a longer clotting time, a decrease in the firmness of the curd and an increase in brittleness. Similar changes noted after heating cow's milk were caused by heat- induced chemical reactions, such as formation of a complex between kappa casein and beta-lactoglobulin and a decrease in soluble calcium content. These reactions decrease the response of the medium to the action of milk clotting enzymes (Webb, Johnson and Alford, 1974; Ramet, 1985a; Eck, 1990).

A progressive decrease in the propensity of the curd to whey off during draining has been noted, related to an increase in the time-temperature conditions used during heating (Figure 9). This development of the coagulum originates mainly from the higher water-binding capacity of the whey proteins caused by heat denaturation. The curd subsequently remains more moist and crumbly and the dry matter losses in the whey increase in relation to the brittleness (Table 11).

With regard to the above observations, it appears necessary to regulate the heat treatment of camel milk according to the total solids content required in the cheese at the end of draining. Milk to be processed into fresh or soft cheese should be heated

under low pasteurization conditions (72 to 76°C for 15 to 30 seconds), whereas for production of less moist cheese such as semi-hard and hard types, thermizing at 62°C for one to two minutes only should be carried out.

Another factor to be taken into account when determining heat treatment conditions is the total solids content of the milk. The adverse effects have a more negative effect on milks with lower dry-matter and casein contents than those richer in these components. Camel milk produced in the hot season by animals short of food and water has poor cheese-making capability (see Composition of camel milk on p. 3 and Coagulation on p. 11). Such milk should not be heated, to avoid further reduction of its cheese-making capability. Hygiene and technical risks during processing mean that these poor milks should be rejected. For other milks with higher total solids and casein content, it may be sufficient to balance the time-temperature conditions of heat treatment with the seasonal variation in milk composition. Further experience of cheese making is required to establish these parameters in relation to the other limitations of the cheese-making process, such as yield and taste and texture quality.

The heating equipment must be capable of providing even treatment throughout the milk. Special plates or tubular heat exchangers are best suited for this operation. When a kettle heated over a fire is used for small-scale processing at family or household level, the milk must be stirred continuously during the heating process in order to avoid localized overheating next to the vessel wall.

It must be remembered that acid milk coagulates when heated, leading to precipitation of casein on the heating surfaces. The acidity of the milk should thus be checked by titration or pH meter before heating starts. Milk of more than 0.22 percent titratable acidity or of less than pH 6.50 should be neutralized before heating.

Neutralization can be carried out using sodium hydroxide on the basis that 40 g of sodium hydroxide (NaOH) will neutralize 90 g of lactic acid. The following example illustrates the calculation:

The cheese maker wants to reduce the acidity of 100 litres of milk from 0.30 percent (30° Dornic) down to 0.16 percent (16° Dornic). A simple calculation shows that the total amount of acid contained in the 100 litres of milk is:

0.30 - 0.16 = 0.14 kg of acid

(30°D - 16°D) x 100 kg = 1 400° D = 140 g of acid

The quantity of sodium hydroxide needed to neutralize this amount of acid is:

40x 100/90= 62.2 g NaOH

The procedure used for neutralization is as follows:

- **accurately weigh out the dry sodium hydroxide;**
- **dilute the quantity in 0.2 to 0.5 litres of water;**
- **stir the milk by hand or with a mechanical agitator;**
- **slowly add the solution to the milk, stirring continuously for one to two minutes;**
- **check the result by acid titration.**

Control of fat content

The composition of cheese depends mainly on the total solids, or dry-matter content, and the fat content. The total solids content of 100 g of cheese is measured by the

weight of dry matter left after evaporating the water in an oven. The fat content is usually determined by the Gerber method, with the result expressed as a percentage of the dry-matter content of the cheese (Fox, 1987; Lambert, 1988; IDF, 1990).

In cheese making, the fat and total solids contents are controlled to ensure standard taste and texture properties. The composition of the cheese may have to comply with national regulations, where they exist.

The amount of fat in cheese is regulated by controlling the fat content of the milk prior to coagulation. The dry-matter content is subsequently adjusted by controlling the factors regulating the draining and ripening of the curd (Ramet, 1985c; Robinson, 1990a). The fat content in the whole milk is higher relative to the average amount of fat required in most cheese varieties. The milk must therefore be partly skimmed. This may be carried out by natural creaming or by scooping off the cream which has risen to the top of the milk after it has stood for a few hours at room temperature. A more efficient method is to separate off a calculated amount of cream in a milk centrifuge. This is known as standardizing and can be carried out either by continuously separating the excess fat or by batch process, mixing calculated amounts of whole and skimmed milk in the cheese vat.

The amount of fat required in the standardized milk is calculated as follows:

$$FMSM = (FMC \times G)/SNFC + FMW$$

FMSM = fat content of standardized milk;

FMC = fat content of cheese (percentage dry matter);

SNFC = non-fat solids content of cheese (percentage dry matter);

G = coefficient of recovery of non-fat milk solids in cheese (g/litre);

FMW = fat content of whey (g/litre).

Example:

The cheese maker wants to standardize the fat content of camel milk to make a cheese with 30 percent fat in total solids. Other information required for the calculation is:

fat content in whole camel milk = 27 g/litre;

G coefficient = 25 g/litre;

FMW = 8 g/litre.

The required fat content of the standardized milk will be:

(30 x 25)/70 + 8 = 19 g/litre

The total amount of fat required in the cheese vat:

100 litres x 19 g/litre = 1 900 g

Batch ratio (whole to skimmed milk):

whole milk: 1 900/27 = 70.5 litres;

skimmed milk: 100 - 70.5 = 29.5 litres.

Procedure:

- **determine fat content in the whole milk by the Gerber method;**
- **calculate the proportion of whole and skimmed milk as described above;**
- **subtract from the skimmed milk quantity the volume of liquid lactic starter to be inoculated into the milk for coagulation;**
- **accurately measure the volume of whole and skimmed milk into the vat;**
- **carefully stir the batch to obtain uniform milk composition.**

Correction of dry-matter content

One of the most critical factors involved in processing camel milk into cheese is its low total solids content and unique casein and calcium composition. In practice, it is possible to use corrective methods, singly or together, to prepare the milk for processing into cheese.

Increasing casein concentration. **Different techniques may be used to increase the relative concentration of casein in milk. The aim is to reduce coagulation time and improve the rheological properties of the curd.**

Evaporation of milk. **In principle, the method consists of concentrating the dry matter in milk by partial evaporation of water. In order to avoid the damaging effects of high heat on curd clotting and draining (see Milk preparation on p. 18), low temperatures (45 to 60°C) should be maintained. Such operations may be carried out at the household level at atmospheric pressure in the open in small containers. At the industrial level, vacuum evaporation is better, because it enables higher outputs, improves yields and reduces**

costs. In both cases, the optimum concentration is between 15 and 20 percent total milk solids.

Concentration by ultrafiltration. **Ultrafiltration is a more advanced procedure for concentrating casein in milk. In view of its widespread industrial use with cow's milk, it should be possible to raise the protein content of camel milk to between 3.6 and 3.8 percent. No definite information or practical experiences have been published about ultrafiltration of camel milk. It is emphasized that ultrafiltration remains a sensitive process requiring thorough cleaning and disinfection procedures, complete safety in feeding fluids to the system and skilled technical staff. Most of the equipment currently available on the market has a very high capacity and is unsuitable for small-scale production. For these reasons, ultrafiltration has to be reserved for industrial-scale production.**

Adding milk powder. **Fortifying camel milk solids with milk powder improves the clotting time and causes a significant improvement in curd firmness. Camel milk can thus be processed in a better technical condition (Ramet, 1987). The amount of milk powder to be added is around 4 to 8 percent. This hardly alters the taste and texture quality of the cheese and does not increase the cost. Low- and medium-heat powders should be used.**

Another interesting alternative could be to use dry milk retentates obtained by ultrafiltration or dehydration. The technology is complex, however; dried retentates are expensive and not readily available.

Production of powder from camel milk has not been investigated, even on a pilot scale (Abu-Lehia, 1994). It is therefore unavailable and milk powder of bovine origin has to be

used. The mixture of the two types of milk reduces the authenticity of cheese made from pure camel milk. Local regulations concerning possible adulteration need to be taken into account.

Adding fresh milk from other species. **eographically, goats, sheep, zebu cattle and buffaloes are often bred in association with camels. The milks of these animals are suitable for cheese making because of their casein and calcium content. Mixing these milks with camel milk has been suggested as a means of enhancing the processing properties of camel milk for cheese making.**

Field trials carried out in Saudi Arabia (Ramet, 1990) and Mauritania (Ramet, 1994b) have concluded that fortifying camel milk with sheep's milk at levels of 10 to 50 percent has a beneficial effect on coagulation and draining:

- **clotting time is significantly altered; for example the time is reduced by about 30 percent after adding only 10 percent sheep's milk (Figure 10);**
- **curd firmness, measured by empirical and instrumental methods, is doubled after adding only 10 percent sheep's milk (Figure 11);**
- **curd draining - the time needed to obtain a volume of whey equal to 50 percent of the processed milk - is reduced by about 20 percent after adding 10 percent sheep's milk (Figure 12);**
- **acidity development is accelerated after adding 10 percent sheep's milk (Figure 13), which reduces the buffering capacity of the mix compared with camel milk alone;**
- **the recovery rate of milk solids in the cheese is significantly increased; after enriching camel milk with 10 to 50 percent sheep's milk, recovery reaches 42 and 56 percent, respectively, instead of only 37 percent for the pure camel milk control (Figure 14; Table 12).**

The positive effects on coagulation and draining are explained by the improved curd structure resulting from the high solids of sheep's milk (28.9 percent) and clotting materials (casein, insoluble calcium). Mixing sheep's milk with camel milk brings considerable benefits to the processing of camel milk into cheese, even when small amounts are used. The simplicity of the method makes it very easy to use on both the small and the industrial scales. As stated above, however, the product loses its integrity as a pure camel-milk product as result.

Salt balance correction

Adding calcium salts.**The presence of ionic calcium is essential to complete the secondary phase of the clotting process and to structure the network of casein micelles leading to curd formation (see Enzyme coagulation on p. 11; Webb, Johnson and Alford, 1974; Ramet, 1985b; Eck, 1990). Because a unique salt balance exists in camel milk, the addition of a soluble calcium salt, such as a chloride or monophosphate, produces a significant reduction in clotting time and reinforces gel strength (Ramet, 1985b; Ramet, 1987; Ramet, 1990; Ramet, 1994a). The positive effect of these salts is explained by the consequent pH decrease (Figure 15), which enhances the proteolytic activity of the milk-clotting enzymes, and by the fact that enrichment in calcium ions generates additional links, which strengthen the cohesion of the casein micelle network (Figure 16).**

Depending on the calcium salt concentration, the effect is 15 to 20 percent higher in camel milk compared with cow's milk. Calcium monophosphate is more efficient than calcium phosphate (Ramet, 1985b). From a practical cheese technology standpoint, the addition of calcium salts has to be limited to 10 to 15 g per 100 litres of milk to avoid development of soapy and bitter flavours. These amounts reduce clotting times by 20 to

25 percent compared with control milks (Ramet, 1985a; Farah and Bachmann, 1987; Ramet, 1990; Ramet, 1994a).

In order to ensure uniform dispersion of the calcium salts in the milk and to achieve the required change in salt balance, the calcium salts have to be added at least 30 minutes before the milk-clotting enzyme. If this lead time is observed, the calcium salts have less influence on coagulation (Mohamed *et al.* 1990).

When milk is heated at the beginning of the manufacturing process to improve cheese quality (see Heat treatment on p. 18), the calcium salts must be added to the milk after thermizing or pasteurizing and subsequent cooling to clotting temperature. The added calcium salts will otherwise be precipitated and their enhancing effect lost.

The calcium salts must be of food grade to avoid bad flavours and toxic minerals in the cheese. For this reason, unrefined salts should not be used. Calcium chloride of cheese-making quality is readily and cheaply available on the market in dried form (powder or granules) or as an aqueous concentrate (510 g/litre). Calcium monophosphate should be used in powder form. It has a lower solubility and a higher price than calcium chloride and is not so readily available.

***Adding sodium chloride.*Milk is sometimes salted with sodium chloride for protection against spoilage by various microorganisms. The amount of salt required to reduce water activity enough to prevent microbial growth is 4 to 5 percent (Ramet, 1985b). Sodium chloride causes major changes to clotting times depending on the concentration added. At very low rates of up to 0.3 percent, a slight improvement of up to 15 percent for the coagulation process is obtained for rennet and bovine pepsin coagulants. When salting percentages are above these values, clotting times are**

increased. At rates over 0.6 percent NaCl, coagulation is longer than for unsalted control milk (Ramet, El-Mayda and Weber, 1982; Ramet and El-Mayda, 1984).

The positive effect of sodium chloride at low concentrations is explained by the reduction in pH, which enhances enzyme action. At higher concentrations, sodium chloride has a mainly dissociating action on casein micelles and enzymic proteins (the salting out effect), which adversely affects curd formation.

The effect of sodium chloride on cow's milk is not the same in the presence of different types of milk-clotting enzymes (Hamdy and Edelsten, 1970; Ramet and El-Mayda, 1984). A similar situation has been found for camel milk. Bovine pepsin appears less sensitive to NaCl than calf rennet, particularly at high concentrations (Figure 18).

The rheological properties of gels are also influenced by the presence of sodium chloride in the same manner as clotting enzymes. At the lowest concentrations, firmness is improved and brittleness reduced. At medium and high concentrations, the effects are opposite and cause a decrease in gel strength and an increase in brittleness. These changes are more significant for calf rennet than for bovine pepsin (Ramet, 1990).

Salting camel milk at a concentration of 0.3 percent may thus be recommended to improve clotting. The benefit is limited in practice, however, by the fact that sodium chloride increases water retention in curd and reduces draining ability. The method can therefore only be used for production of moist cheese and some soft cheese (Ramet, El-Mayda and Weber, 1982; Ramet and El-Mayda, 1984; Ramet, 1985c). Whey drained from salted curd contains about 3 g/litre of sodium chloride, which should not affect its economic value.

COAGULATION

Choice of milk-clotting enzymes

Experimental work in Saudi Arabia (Ramet, 1985a; Ramet, 1990) and Tunisia (Ramet, 1987) has shown that different commercial milk-clotting products do not all have the same ability to coagulate camel milk (Figure 2). Of the enzymes, bovine pepsin has been identified as the best for clotting camel milk. Calf rennet and milk-clotting enzyme extracted from the mould *Mucor miehei*have slightly less effect. Other observations (Gast, Maubois and Adda, 1969; Yagil, 1982; El Abassy, 1987; El-Batawy, Amer and Ibrahim, 1987) corroborate the advantage of pepsin for coagulating camel milk.

A characteristic common to all pepsins is that they are more active than chymosin and rennet in acid media. Clotting activity decreases rapidly at pH levels above 6.3. At the pH of fresh milk (6.65 to 6.75), clotting does not occur. Similar behaviour has been observed in both cow's and camel milk (Figure 19). Results indicate that the milk must be acidified to pH 6.2 to 6.5 prior to coagulation in order to achieve the best effect. It must be noted, however, that such an increase in acidity results in demineralization of the casein micelles, which in turn increases curd fragility and makes draining more difficult. For these reasons, milk to be used for processing into fresh and soft cheeses can be acidified as described above. For semi-hard and hard cheeses, it is advisable to limit acid development in relation to the total solids anticipated in the cheese to pH 6.4 to 6.5 for semi-hard cheese and pH 6.5 to 6.6 for hard cheese.

Pepsin has a high non-specific proteolytic activity, which may produce bitter peptides in the cheese during ripening, depending on the amount of residual milk- clotting

enzymes. This is itself conditioned by the pH value and the total proteolytic potential introduced elsewhere into the cheese by microflora. It is well known that bitterness appears more frequently when the pH of the cheese is lower than 5.2 and when the microbial activity is low.

The bitter peptides mainly originate from beta-casein hydrolysis, which is relatively high in camel milk. Observations indicate, however, that the bitterness is no more common in camel cheese than in cheese made from other milk.

No definite information exists of any reactions that could limit the use of pepsin to produce camel cheese. Calf rennet and fungal protease from *Mucor miehei* ffer lower risks and could thus be preferred to pepsin, in spite of their weaker ability to clot camel milk.

Reducing pH

Milk-clotting enzymes are acid proteases whose optimal activity is generally close to pH 5.5 (Ramet, 1985a; Eck, 1990). From the literature, it appears that fresh camel milk pH varies fairly widely from 6.55 to 6.85, depending on origin and local production factors (Farah, 1993; Jardali, 1994). These pH values are not particularly suitable for good clotting. It is thus beneficial in cheese making to acidify the milk slightly at the time of adding enzyme. It can be demonstrated (Figure 19) that increasing milk acidity from pH 6.66 to 6.40 decreases the clotting time by 28 percent, when using rennet, and 70 percent, when using bovine pepsin.

Various procedures can be used to reduce pH value:

- **The simplest method consists of inoculating the milk with 1 to 2 percent lactic**

starter culture with a titratable acidity of 0.8 percent. This reduces pH by 0.10 to 0.15 pH units. If this reduction is too small, the milk should be left at 28 to 35°C for further acid development by the lactic acid bacteria. The ripening time may be increased by 30 to 90 minutes depending on starter activity and the acidity required at the start of coagulation.

- **A second widely used method decreases pH by means of calcium or sodium salts. The dosage rates are mentioned in Salt balance correction on p. 21.**
- **A third method is to add an external organic acid to the milk. Acids with strong, distinctive flavours (citric acid, acetic acid, etc.) should be used only at low concentrations. Food-grade lactic acid is best-suited for adjusting pH. Pouring must be carried out slowly while the milk is being vigorously stirred. If the turbulence is not strong enough, casein precipitates at the point of pouring the acid into the milk. The acidity level must be checked regularly during dosing to achieve the required pH or titratable acidity.**

When food-grade acid is not available, an alternative practical method could be used which involves adding acid whey (1.2 to 1.8 percent lactic acid) obtained from previous cheese making. Prior to adding the acid whey, the existing lactic acid bacteria present in the camel milk should be destroyed by pasteurizing at 72 to 76°C for one minute to prevent excessive growth during milk processing. This procedure dilutes the concentration of the milk components, however, so it must be limited to small pH adjustments.

Two new methods for adjusting pH value at renneting have recently been developed and used in industrialized countries. The first acidifies the milk with gluconic acid produced from aqueous hydrolysis of glucono delta-lactone (GDL). The second is based on the fortification of carbonic acid in milk by injecting purified carbon dioxide.

The gas is readily soluble and induces a rapid pH decrease.

Increasing acidity generates a corresponding demineralization of the casein micelles in addition to the pH decrease. This development, in turn, causes a gradual decrease in curd elasticity and draining ability. The reduction of pH must therefore be carried out with caution using the narrow, well-defined limits for each cheese variety (see Summaries on p. 28).

In some African countries milk, including camel milk, is stored in wooden containers, which are scoured with charcoal or heated over an open fire. It seems that this could cause a small decrease in pH (of 0.1 to 0.2 pH units) resulting from the dispersion of organic acids in the milk. Milk treated in this way, and the resultant cheese, have a characteristic smoky flavour (Mohamed, 1990; Ramet, 1995).

Increasing the clotting temperature

The optimum temperature for most milk-clotting enzymes is around 40 to 45°C. Above this range, the enzyme is progressively deactivated up to 65°C, when denaturation is total (Ramet, 1984; Eck, 1990). Between 25 and 40°C, a linear relationship exists between temperature increase and the reverse of clotting time. Using rennet as a coagulant, for example, will decrease the clotting time of cow's milk by about 70 percent at temperatures within the above limits. There is a similar tendency with camel milk, but the decrease is limited to 50 percent (Farah and Bachmann, 1987).

In practice, it is possible to capitalize on this property in order to reduce clotting time. The degree of reduction is determined by three factors:

- **sufficient heat to develop the lactic acid bacteria required for the acidity profile of**

each type of cheese;
- reduction in rheological properties of the curd resulting from a loss in viscosity as the temperature rises;
- higher temperatures during draining, leading to dryer cheese.

The possibility of increasing temperature is feasible, but only by 3 to 5°C.

Increasing the amount of milk-clotting enzyme

For most milk-clotting enzymes, a linear relationship exists between clotting time and the reverse of enzyme concentration. If the amount of enzyme is doubled, the clotting time is reduced by half (Ramet, 1985b). In practice, this adjustment should be employed with care, because altering the enzyme concentration upsets the delicate balance between acid and enzyme makeup, which defines any cheese-making process. Overdosage of the milk-clotting enzyme invariably causes a granular curd texture and the development of bitterness resulting from accumulation of bitter peptides.

A further consideration in limiting enzyme concentration is that the clotting ability of camel milk is reduced more than for the milk of cows, sheep, goats or buffalo. As previously mentioned, this situation calls for an increase in enzyme concentration in order to obtain comparable processing times. It is not advisable, however, to increase the clotting enzyme amount significantly.

DRAINING

Methods

The chief feature of the camel milk coagulum during draining, even after remedial treatment, is that it depends mainly on the brittleness and the low elasticity of the curd. Physical treatment applied during the earlier stages of draining should thus be carried out with care, to prevent any damage and unwanted curd disintegration.

A well-fortified coagulum is needed at cutting, which must be done with care. These conditions are essential to prevent the curd from disintegrating into small particles that will be lost in the whey. The moulding technique should not cause further curd breakage. Methods used to ensure proper draining depend on the type of cheese to be processed:

- **For soft, semi-hard and hard cheeses, firmer curd grains are essential to ensure that they will not be further crushed on the draining surfaces by cloths, moulds or plates. The size of cut of the curd grains must thus be reduced compared with cow's milk curd to ensure production of standard cheese. The curd grains should be left to whey off for a longer period in the cheese vat. Both these processing modifications produce a significant increase in the total solids of the curd, which reinforces the cohesion of the casein network (Ramet, 1985a; Ramet, 1991; Ramet, 1994b).**
- **For fresh cheeses with a water content of more than 65 percent and high curd fragility, direct filling into cheese moulds is difficult because of high curd losses through the holes on the bottom and walls of the moulds. In order to avoid these unwanted effects, the curd should first be drained in muslin cloths or bags. Muslin ensures good curd retention and whey filtration. Two to three hours later, moulding of the partially drained curd can be carried out without further excessive curd losses (Ramet, 1995).**

These modifications are particularly called for when the milk to be processed has a low total solids content. This situation occurs often in the hot season when milk is collected from animals under feed and water hardship (Ramet, 1990; Ramet, 1991; Ramet, 1994b; Ramet, 1995).

After moulding, subsequent draining of camel milk curd is characterized by several distinctive features:

- **Large amounts of curd soon stick to the draining surfaces, cloths and mats. To prevent this, the first turning of the cheese mould must be done as soon as possible, preferably within 15 to 30 minutes of filling. The second turning must be carried out 30 to 60 minutes later. In order to reduce curd sticking and ensure better whey seepage, a good solution is to put an additional cloth (cotton turban cloth, curtain cloth, etc.) on the draining mat, removing it after the second turning (Ramet, 1994b; Ramet, 1995).**
- **Compared with the draining of curd from other milk, wheying off camel milk curd is much faster. Whey drainage is generally complete within six hours of moulding. When draining is continued for a further 16 to 24 hours using the common method for other milk, camel cheese becomes very dry, with a hard, chalky texture. The higher water content of camel milk and the reduced water-binding ability of the casein are probably the causes. To avoid this, cheese-making techniques that reduce wheying off should be used, such as lowering the temperature of the draining room or reducing the number of turns and the level of acidity. It must be stressed that these techniques should not be allowed to inhibit acid development, and hence the effect of pH depression in the cheese, too much (Ramet, 1990; Ramet, 1995). Some of the techniques proposed to improve the coagulation ability of camel milk, such as heat treatment or enrichment with whey proteins, have the**

secondary effect of increasing curd hydration and slowing down whey drainage.

- **At the end of draining, the absorption of salt into camel cheese is much faster than into cheese made from other milk (Ramet, 1987; Ramet, 1990; Ramet, 1994b). As a result, cheese texture becomes hard and the taste too salty. It appears that this original effect could be the result of several factors, such as a lower fat content resulting from high fat losses in the whey, a weaker casein water-binding capacity and larger micelles (Ramet, 1994b; Ramet, 1995). In order to avoid these defects, the amount of salt to be added to the cheese must be carefully checked. It is preferable to salt by dipping the cheese in brine. The exact salt level can then be accurately determined by regulating the time the cheese is in the salt bath. Compared with similar cheese made from cow's milk, the salting time is reduced by about half for soft cheese (Ramet, 1994b; Ramet,).**

Cheese yield

Cheese yields under experimental cheese-making conditions indicate that the recovery of milk solids in the cheese depends largely on milk origin and cheese type. For semi-hard cheese manufactured in the hot season from milk with a poor dry-matter content, the percentage of solids recovered is low (31.7 percent) and similar to the level measured without corrective treatment (Ramet, 1987). When corrective treatments such as pasteurizing and adding calcium salt are used on milk from intensively managed animals, recovery is improved to 45.7 percent (Table 13).

For soft cheese made from milk produced by camels managed under extensive systems, solids recovery varies from 38.0 percent at the end of the hot season to 42.0 percent at the beginning of the cold season (Ramet, 1994b; Ramet, 1995). When camel milk is enriched with sheep's milk at rates of 30.0 and 50.0 percent, recovery is greatly

improved from 33.3 percent to 55.1 and 58.1 percent, respectively.

The recovery of dry matter in fresh cheese is higher than in other cheese, mainly because the whey solids are more strongly held in the curd. For example, when camel milk is processed after pasteurization and addition of modified milk-clotting enzyme and calcium salt, recovery reaches 56.0 percent (Ramet, 1994a).

The weight of cheese produced from 100 litres of milk is dependent on the moisture content of the cheese and the level of recovery of the milk solids. On average, the yield for semi-hard and soft cheese is some 10.5 to 10.7 kg per 100 litres of milk when the milk solids are high (Table 13; Ramet and Kamoun, 1988; Ramet, 1994b). When the quality of the raw milk is poor, yields decrease markedly to as low as 6.7 percent (Ramet, 1987). For fresh cheese made from good-quality milk, the yield reaches 26.0 percent (Ramet, 1994b).

Whey

Whey drained from camel milk has a characteristic white colour. Its total solids content averages 6.9 to 7.0 percent, of which 1.2 to 1.3 percent is fat (Ramet, 1987; Ramet, 1994b). The amount of solids loss in whey can be reduced during processing by using milk with high total solids and being careful with mechanical treatment during clotting and draining. The filtration force at draining greatly influences the solids losses, with higher rates producing better recovery and lower fat levels of around 0.6 percent (Ramet, 1995).

The total amount of whey produced during draining is important. It varies as the reverse of cheese weight and comprises between 70 and 90 percent of the quantity of

processed milk for fresh, soft and semi-hard cheeses, respectively.

RIPENING

Data on the ripening of camel milk cheese is very limited, because little scientific research has been carried out into this relatively new subject. Only general observations have been made during trials on a laboratory or pilot scale. Very little specific information has been published on ripening time, the main compositional factors regulating enzyme potential or the changes in cheese composition caused by the enzyme reactions.

Experimental results indicate that taste and texture quality develops in a similar way to cheese produced from cow's milk. An important distinction concerns the development of a more crumbly, chalky cheese texture. These properties are probably the result of the lower fat content and reduced water-binding capacity of the casein. Another factor, which has occasionally been reported when the cheese is consumed, is a greasy sensation in the mouth (Ramet, 1987; Ramet and Kamoun, 1988; Mehaia, 1994). This defect is assumed to originate from the fatty acid composition of camel milk fat and from interactions involving mouth temperature and the melting point of the fat.

For cheese ripened for several days in the open at ambient temperature, water evaporation from the curd is deeper and faster in camel milk cheese than in cheese from other milk. These developments lead to the formation of a crusty surface and hard texture, which are probably linked to the specific effects of fat and casein which facilitate the migration of free water towards the surrounding atmosphere. As camel milk cheese is more sensitive to water balance, the relative humidity of the ripening

room or container must be accurately controlled at between 90 and 95 percent. Such control is difficult in dry desert environments where the humidity is often as low as 15 to 20 percent (Ramet, 1995).

Another important factor is that the growth of microbial flora involved in ripening is determined by water activity (Aw), mainly on the surface of the cheese. If air humidity drops below 65 percent, surface water activity stabilizes at 0.65, inhibiting development of microorganisms according to their sensitivity to Aw. The development of cheese composition and taste quality ceases and ripening does not progress normally.

For cheese that is mainly ripened by fungal flora composed of *Penicillium camemberti Penicillium roqueforti*and *Geotrichum lactis* the visual growth and appearance of the mycelia have been judged satisfactory for various types of cheeses such as Camembert (Ramet, 1987; Ramet, 1990; Mehaia, 1994b; Ramet, 1994; Ramet, 1995), fresh cheese (Ramet, 1987) and semi-hard cheese (Ramet, 1991).

On some batches of hard cheese, slower development of the microflora has been noted. It has not been clearly determined whether this originates from the effect of water activity or from residual activity of the strong antimicrobial capacity of the raw camel milk (Ramet, 1994b; Ramet, 1995).

The taste of cheese made from camel milk varies according to ripening time and cheese type. For fresh cheese consumed immediately after draining and salting without ripening, the taste profile is neutral, without any distinctive characteristic. For young soft cheese and semi-hard cheese, similar results have been found (Ramet, 1987; Ramet, 1994b).

For soft cheese ripened with *Penicillium camembertia*s the dominant flora, a distinctive, original taste develops with time as the chemical transformation of the curd occurs. This flavour, which is completely different from similar cheese made from cow's milk, is accepted positively by testers (Ramet, 1994b; Ramet, 1995).

A slight to moderate bitterness has sometimes been noted in all cheese types during the early stages of ripening. This generally disappears as ripening develops. The origin of the defect has not been clearly identified. It could be caused by the effect of high levels of calcium salts used for improving the coagulation process and/or the accumulation of bitter peptides formed by residual proteolytic activity of the milk-clotting enzymes and the resultant low pH value (Ramet, 1987; Ramet and Kamoun, 1988; Kamoun and Bergaoui, 1989).

The salty and/or bitter taste sometimes detected in some batches of camel milk cheese originates from particular forage species. It has not been determined whether the bitter substances are eliminated with the whey and/or masked by the other cheese flavouring components (Ramet, 1987).

Methods of processing camel milk into cheese

To produce high quality cheese, it is necessary to follow routine practice common to

the production of all cheese types. Only the basic steps are outlined below. For more detailed information, reference should be made to specialized publications on the subject (Alais, 1984; Veisseyre, 1975; Ramet, 1985c; Scott, 1986; Fox, 1987; Robinson, 1990a; Eck, 1990). Later in this chapter, processing methods for the main types of camel milk cheese are summarized.

GENERAL GUIDANCE

Basic milk-processing parameters

To achieve a good-quality product, the following recommendations should be followed:

- **select milk with good chemical and microbial quality;**
- **make the cheese in a clean, dust-free environment;**
- **use properly cleaned and disinfected utensils;**
- **employ healthy, clean, trained staff;**
- **enhance the processing capability of camel milk by corrective treatment such as heating and/or adding solids and calcium salt (see Milk preparation on p. 18);**
- **systematically check the main processing factors controlling production;**
- **use only additives (lactic starters, milk-clotting enzymes, salts, etc.) of food-grade standard with good chemical, microbial and technical properties;**
- **store heat-sensitive additives under refrigeration to limit activity loss;**
- **keep perishable raw materials and manufactured products under cool conditions and protected from light, dust and rodents;**
- **reject defective or questionable raw materials and products.**

Preparing and using lactic starters

Using the right lactic starter ensures authentic taste and hygienic quality. For cheese made from raw milk, lactic starter addition is recommended to boost the natural population of lactic acid bacteria and inhibit harmful flora such as coliforms and psychrotrophic and pathogenic bacteria. For cheese made from heat-treated milk, lactic starter addition is mandatory to develop proper acidity, drainage and acid preservation of the curd.

Lactic starters can be prepared by simple methods adapted either for household or for industrial production. The recommended method of preparation is as follows:

- **select the growth medium, which can be either fresh milk with good bacteriological and chemical quality or reconstituted milk obtained from dissolving 10 percent skimmed milk powder in potable water;**
- **pour the reconstituted milk into containers for sterilization;**
- **sterilize the milk at 100 to 120°C for ten to 20 minutes;**
- **cool down to the incubating temperature;**
- **inoculate the milk under aseptic conditions with the mother culture at the rate of either 0.5 g of dry culture per 0.5 to 1 litre, or 20 ml of liquid culture per 0.5 to 1 litre;**
- **incubate in an incubator or at room temperature: mesophilic starters at 25 to 35°C for eight to 12 hours, thermophilic starters at 42 to 45°C for two to four hours;**
- **halt incubation when the acidity reaches 0.7 to 0.9 percent lactic acid or pH 5.0 to 5.5;**
- **cool down and keep the starters under refrigerated conditions (0 to 4°C) until used;**
- **avoid long storage periods, which reduce lactic acid bacteria viability;**

- **keep the mother cultures at deep freezer temperatures (-40 to -80°C).**

Adding cheese-ripening moulds

Some types of cheese are traditionally ripened with moulds that develop either on the surface (fresh, soft and some semi-hard cheeses) or in the body of the cheese (blue cheeses). Traditionally, the uptake of moulds occurs through natural inoculation when the cheese is left out in the ripening room, which is full of spores. This method is risky, however, and causes inconsistency in appearance and taste of the cheese. It is better to use a more controlled inoculation of commercially available complementary exogenous cultures, obtainable in dried or liquid form.

The dominant organisms in the surface flora are strains of *Penicillium*, *Geotrichum* and, occasionally, *Mucor*. These moulds are often also associated with yeasts and bacteria. *Penicillium camemberti* is widely used and gives a typical white appearance to many soft cheeses, such as Camembert or Brie, and to some semi-hard cheese such as White Tomme. *Penicillium roqueforti* is the typical mould that develops in blue cheeses, growing in the holes in the cheese curd.

Inoculation of spores is carried out by two methods:

- **in the milk prior to coagulation by mixing an appropriate quantity of commercial strains;**
- **on the surface of the salted cheese, either by soaking in a solution of spores in sterile water or by spraying the solution over the whole surface.**

Equipment used for inoculation must be thoroughly cleaned and disinfected to avoid contamination by spoilage organisms. The spore concentration is adjusted according to

the method given by the manufacturers.

Because the moulds used in cheese ripening are highly aerobic, the cheese is placed on trays or wooden boards, which allow good all-round surface aeration. During ripening, the cheese is regularly turned to ensure even growth of the mycelium. Other environmental factors also need to be closely regulated to optimize mould development. The temperature is usually set between 12 and 14°C, except for blue cheese when it is set at 6 to 7°C. The relative humidity is set between 85 to 95 percent, depending on the sensitivity of the microflora to water activity. Under these conditions, mould growth is quite slow. The mycelium becomes visible after four to six days; full development takes up to 15 to 25 days.

The proteolytic and lipolytic potential of mould enzymes is important and influences significant biochemical changes in the composition and taste of the cheese.

Characterizing and using milk-clotting preparations

The activity of commercially available milk clotting preparations is determined in cheese making by clotting strength, which corresponds to the ratio between a defined amount of the preparation (volume for liquid preparations, weight for dried preparations) and a defined amount of milk to be clotted under precise time-temperature conditions. The standard reference used in Europe indicates that 1 kg of powdered rennet, labelled with a strength of 1/150 000, will coagulate 150 000 litres of milk at 35°C within 40 minutes.

The strength of liquid preparations declines slowly at ambient temperature (15 to 45°C) and refrigerated storage (0 to 6°C) is recommended. Dried preparations are less sensitive, but refrigeration is advisable for prolonged periods of storage.

The clotting enzyme quantities indicated in the following summaries for processing camel milk into cheese are given with reference to enzyme preparations with a strength of 1/100 000. When preparations with different strengths are used, the amount should be corrected according to the strength ratio.

SUMMARIES

The following summaries of making the main cheese types are based on production trials in the field carried out during missions supported by FAO. The processing summaries are based on laboratory experiments in Saudi Arabia (Ramet, 1985a; Ramet, 1990), pilot production in Tunisia (Ramet, 1987) or commercial production in Mauritania (Ramet, 1994b; Ramet, 1995).

The results indicate that camel milk is not readily processed into cheese compared with milk from other dairy animals. This results mainly from its low total solids content, unique composition and casein properties. Its suitability for cheese making decreases significantly in the hot season, when camel milk production is influenced by water and feed availability.

The summaries have been modified to cover processing of poor-quality milk. It is thus recommended that both heat treatment and calcium salt enrichment be employed. To effect the changes set out in Chapter 3, the other corrective steps may be applied. It is also crucial to stress that these additional corrective steps become less essential as the quality of the camel milk for processing improves.

Fresh (cottage) cheese	
CHARACTERISTICS	
Raw material	Camel milk
Type	Fresh cheese
Shape	Various, depending on container shape
Weight	Various, depending on container size
Appearance	Soft, white, moist paste
Taste	Acid
Dry matter	18-30%
Fat	10-30%
TECHNOLOGY	
Milk preparation	
Fat adjustment	Use whole or partly skimmed milk, fresh or slightly acid
Heat treatment	Thermizing (62-65°C for 1 min) or low pasteurizing (72-75°C for 1 min)
Coagulation	
Type	Mainly acid
Clotting additives	
Ca chloride or phosphate	10-15 g/100 kg liquid milk

Mesophilic lactic starters	Liquid form: 1-3 kg/100 kg milk; dried form: 1-3 g/100 kg milk
Clotting enzyme	0.4-1.0 g/100 kg milk
Acidity at renneting	0.16-0.30%, pH 6.8-6.0
Temperature	20-30°C
Clotting time	7-20 hr
Total coagulation time	16-48 hr
DRAINING	
Type	Spontaneous, enhanced by gentle mechanical action
Making sequence	
Cutting	Irregular pieces (1-10 cm)
Moulding	Filter cloths or bags
Pressing	Self-pressing by curd with turning at 20-28°C for 10-24 hr
Salting	Optional dry salting by mixing into curd
Packing	Various containers
Ripening	
Type	Cheese consumed without ripening: optional ripening by surface microflora or air drying
Storage	Unripened cheese at 0-6°C for 5-15 days; ripened cheese at 12-16°C for 10-20 days

Yield	10-28 kg/100 kg milk

Goat-style cheese	
CHARACTERISTICS	
Raw material	Camel milk
Type	Between fresh and soft cheese
Shape	Cylinder or pyramid
Weight	20-200 g
Appearance	Varied; dry or moist surface or with bacterial or fungal microflora
Taste	Acid for unripened cheese; typical camel cheese flavour for ripened cheese.
TECHNOLOGY	
Milk preparation	
Fat adjustment	Whole or partly skimmed milk, fresh or slightly acid
Heat treatment	Thermizing (62-65°C for 1 min)
Coagulation	
Type	Combined, mainly acid
Clotting additives	

Ca chloride or phosphate	10-15 g/100 kg milk
Mesophilic lactic starters	Liquid form: 1-2 kg/100 kg milk; dried form: 1-2 g/100 kg milk
Clotting preparation	2-3 g/100 kg milk
Acidity at renneting	0.16-0.30%, pH 6.8-6.0
Temperature	22-35°C
Clotting time	30-120 min
Total coagulation time	10-24 hr
DRAINING	
Type	Spontaneous, enhanced by gentle mechanical action
Making sequence	
Cutting	Cubes (2-4 cm)
Moulding	Hand-filling into cloths or bags; first draining in bags for 4-8 hr, second draining in moulds for 4-24 hr
Salting	Dry salting on surface, 1.5-2%
Drying	Limited air-drying on surface
Ripening	
Type	Cheese consumed fresh or after short ripening with fungal microflora/optional air-drying

Ripening with moulds	Inoculation with Penicillia and Geotricha strains at 12-25°C for 8-15 days at 85-95% humidity
Dried cheese	Air- and sun drying at 15-40°C for 4-30 days at 15-90% humidity
Storage	Fresh and ripened cheese at 0-6°C for 5-30 days; air-dried cheese at 20-40°C for 1-6 months
Yield	Fresh cheese: 9-18 kg/100 kg milk; dried cheese: 4-8 kg/100 kg milk

Soft cheese	
CHARACTERISTICS	
Raw material	Camel milk
Type	Soft cheese
Shape	Flat cylinder
Weight	150-300 g
Appearance	Uniform paste, some holes, surface microflora
Dry matter	40-50%
Fat	10-30%

TECHNOLOGY	
Milk preparation	
Fat adjustment	Whole or partly skimmed milk, fresh or slightly acid
Heat treatment	Thermizing (62-65°C for 1 min) or low pasteurizing (72-75°C for 1 min)
Coagulation	
Type	Combined, with weak acid effect
Clotting additives	
Ca chloride or phosphate	10-15 g/100 kg milk
Mesophilic lactic starters	Liquid form: 1-3 kg/100 kg milk, dried form: 1-3 kg/100 kg milk
Clotting preparation	4-8 g/100 kg milk
Acidity at renneting	0.16-0.25%, pH 6.8-6.2
Temperature	28-35°C
Clotting time	10-30 min
Total coagulation time	60-90 min
DRAINING	
Type	Spontaneous, enhanced by gentle mechanical action
Making sequence	
Cutting	Cubic grains (1-4 cm), kept in whey for 30-90

	min up to draining off 30-50% whey
Stirring	Slow; periodic for 60 sec every 10 min
Whey extraction	Scooping out 30-50% whey before moulding
Moulding	By hand, into moulds; possibility of gentle mechanical action; 26-28°C for 4-6 hr, 16-22°C for 18-20 hr; turn moulds 3-5 times during draining
Salting	1.5 to 1.8% dry salting on surface or soaking in brine for 10-30 min
Ripening	
Type	With surface microflora; moulds: Penicillia and Geotrichum; bacteria and yeasts: Brevibacterium, Micrococcus, Kluyveromyces, etc.
Temperature	12-14°C
Relative humidity	90-95%
Time	15-45 days
Yield	7-10.5 kg/100 kg milk

Semi-hard cheese	
CHARACTERISTICS	
Raw material	Camel milk

Type	Semi-hard, lactose-free
Shape	Flat cylinder
Weight	1-2 kg
Taste	Smooth, neutral to slightly acid
Dry matter	44-46%
Fat	10-30%
TECHNOLOGY	
Milk preparation	
Fat adjustment	Whole or partly skimmed milk, fresh or slightly acid
Heat treatment	Thermizing (62-65°C for 1 min) or low pasteurizing (72-75°C for 1 min)
Coagulation	
Type	Associated with minor enzyme effect
Clotting additives	
Ca chloride/phosphate	10-15 g/100 kg milk
Mesophilic lactic starters	Liquid form: 0.5-1.5 kg/100 kg milk; dried form: 0.5-1.5 g/100 kg milk
Clotting preparation	4-8 g/100 kg milk
Acidity at renneting	0.15-0.20%, pH 6.8-6.4
Temperature	30-33°C
Clotting time	6-20 min

Total coagulation time	20-60 min
DRAINING	
Type	Spontaneous, improved by robust treatment
Making sequence	
Cutting	Regular grains (0.5-1.0 cm)
Pitching	After 15-30 min to harden grains
Stirring	Periodic for 60 sec every 10 min for 30-45 min
Delactosing	Removal of 20-60% whey, then addition of equal amount of potable water at 30-33°C
Pre-pressing	In wooden or metallic frames for 10-20 min
Moulding	In individual cloths and moulds
Pressing	2-6 hr at 22-26°C
Salting	Dry salting on surface or soaking in brine; salt concentration: 1.5-2.5%
Ripening	
Type	Open air, with/without surface microflora
Temperature	12-16°C
Relative humidity	90-95%
Time	15-45 days
Yield	6-10 kg/100 kg milk

Semi-hard cheese cured in brine	
CHARACTERISTICS	
Raw material	Camel milk
Type	Semi-hard, eaten fresh or after curing in brine
Shape	Oblong portions
Weight	80-500 g
Appearance	Smooth texture without holes, thin crust without surface microflora
Taste	Acid, salty
Dry matter	35-45%
Fat	10-30%
TECHNOLOGY	
Milk preparation/coagulation/draining	As for semi-hard lactose-free cheese, except for curd washing
Salting	Dry salting on surface of unripened cheese; brine or whey soaking for cured cheese (8-16%), allowing 20-25% brine absorption by the end of ripening and packing into clay jars

	or cans
Ripening	
Type	Slow ripening in brine or oil bath
Temperature	15-40°C outdoor, or in air-conditioned rooms
Time	30-180 days
Yield	6-10 kg/100 kg milk

Blue cheese	
CHARACTERISTICS	
Raw material	Camel milk
Type	Blue cheese
Shape	Tall cylinder or oblong block
Weight	0.5-5 kg
Appearance	White paste with numerous holes covered in blue-green Penicillium roqueforti mould
Taste	Strong, piquant, lipolytic
Dry matter	45-50%
Fat	10-30%
TECHNOLOGY	

Milk preparation	As for semi-hard cheese up to the end of stirring, which is continued for an additional 30-45 min to obtain a better drained, hard grain
Moulding	In hanging draining cloths for wheying off for a further 15-30 min, hand crumbling and mixing Penicillium spores, then moulding
Pressing	No mechanical pressing, keeping holes open so mould will grow
Salting	Dry salting on surface for 4-5 days at 6-15°C; salt concentration: 2-4%
Ripening	
Type	Aerobic conditions
Temperature	8-12°C
Relative humidity	90-95%
Time	30-60 days
Special treatment	Pricking at the beginning of ripening to improve growth of Penicillium
Yield	6-8 kg/100 kg milk

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TABLE 1

World camel population by country, density and per capita

Country	Area km2	Human population (thousands)	Camel population (thousands)	Camel density (no./km2)	Camels per capita
AFRICA					
Algeria	2 381 741	24 960	135	0.06	0.005
Burkina Faso	274 200	8 996	5	0.02	0.0005
Chad	1 284 000	5 678	540	0.42	0.095
Djibouti	23 200	409	59	2.50	0.144

Egypt	1 001 450	52 426	190	0.20	0.004
Ethiopia	1 221 900	49 240	1 080	0.88	0.02
Kenya	580 370	24 031	810	1.40	0.033
Libya	1 759 540	4 545	193	0.11	0.042
Mali	1 240 190	9 214	241	0.19	0.026
Morocco	446 550	25 061	43	0.10	0.002
Mauritania	1 025 520	2 024	820	0.80	0.405
Niger	1 267 000	7 731	420	0.33	0.054
Nigeria	923 770	108 542	18	0.02	0.002
Senegal	196 720	7 327	15	0.08	0.002
Somalia	637 660	7 497	6 855	10.75	0.914
Sudan	2 505 810	25 203	2 800	1.12	0.111
Tunisia	163 610	8 180	187	1.14	0.023
ASIA					
Afghanistan	652 090	16 557	265	0.40	0.016
Saudi Arabia	2 149	14 134	405	0.19	0.028

	690				
United Arab Emirates	83 600	1 589	115	1.37	0.072
India	3 287 260	853 094	1 450	0.44	0.002
Iraq	438 320	18 920	59	0.13	0.003
Iran	1 648 000	54 607	27	0.02	0.0005
Israel	20 770	4 600	10	0.48	0.002
Jordan	89 210	3 288	15	0.17	0.005
Kuwait	17 820	2 039	6	0.34	0.003
Oman	212 460	1 502	87	0.41	0.060
Pakistan	796 100	122 626	990	1.24	0.008
Qatar	11 000	368	24	2.18	0.065
Syrian Arab Republic	185 180	12 530	5	0.03	0.0004
Yemen	527 970	11 687	144	0.27	0.012

Source: FAO. Production Yearbook 1990. No. 44.

TABLE 2

Composition of camel milk

	Water	Dry matter	Lactose	Fat	Protein Matter	Ash	Reference
General Values	87.61	12.39	3.26	5.38	2.98	0.70	Barthe, 1905
	87.00	13.00	5.80	2.90	3.70	0.60	Leese, 1927
	86.53	13.47	5.60	3.07	4.00	0.80	Davies, 1939
		12.42	5.40	2.87	3.90		Davies, 1939
	87.50	13.10	5.20	3.02	3.60	0.70	Lampert, 1947
	86.90		5.00	4.50	3.60	0.70	Jenness and Sloan, 1969
	86.30	-	3.30	2.90	3.00	0.60	Wilson, 1984
	to 87.3	-	to 5.8	to 5.4	to 3.9	to 0.8	
Saudi Arabia	86.60		3.90	2.40	2.30	0.75	Sawaya et al., 1984
	to 90.4		to 4.8	to 5.6	to 3.4	to 0.82	
			4.00	3.20	2.50	0.82	Abu-Leiha, 1987
			to 4.7	to 3.5	to 2.8		
Egypt	87.90	12.00	3.90	3.80	3.50	0.80	El-Bahay, 1962
	86.80	13.20	5.50	3.00	3.90	0.80	Davies, 1963
	85.50	14.50	5.00	5.22	3.19	0.80	Taha and Kielvein,

							1989
	86.60	13.20	5.53	3.60	3.27	0.80	Bayoumi, 1990
Ethiopia	85.60	14.30	3.40	5.50	4.50	0.90	Knoess, 1977
	85.90	14.10	4.60	4.30	4.60	0.60	Knoess, 1979
India	86.40	13.61	4.90	3.78	4.00	0.95	Ohris and Joshi, 1961
	87.00	12.98	5.40	3.08	3.80	0.70	Khan and Appana, 1965
	87.00	13.00	5.40	2.90	3.90	0.80	Singh, 1966
Israel	85.70	14.10	4.60	4.30	4.50	0.60	Yagil and Etzion, 1980
	91.20	6.85	2.90	1.10	2.50	0.35	Yagil and Etzion, 1980
Libya	87.00	13.00	4.20	3.30	3.30	0.82	Gnam and Sheriha, 1986
				to 3.6	to 3.6		
Pakistan	86.30	13.30	5.80	2.90	3.70	0.70	Yasin and Wahid, 1957
	87.20	12.80	4.10	4.20	3.70	0.80	Kon and Cowie, 1972
Somalia	86.90	13.00		4.60	3.30	0.60	Mohamed et al., 1989
Sudan				4.00	3.60	0.80	Elamin, 1980

Tunisia	88.60	11.40	4.69	3.55	2.29	0.90	Ellouze and Kamoun, 1989
USSR	86.60	13.67	5.00	4.47	3.50	0.70	Kheraskov, 1953
Average							
Camel Milk	87.37	12.63	4.62	3.70	3.45	0.74	Jardali and Ramet, 1991
Cow's Milk	87.20	12.80	4.80	3.70	3.50	0.80	Webb et al., 1983

**** Milk from camels with limited access to water***

TABLE 3

Average casein composition (%) of camel milk and cow's milk (Tunisia, France, Somalia, Saudi Arabia and the Niger)

Casein fraction	ð	ß	K	Y
Camel milk	63	28	5	2
Cow's milk	46	34	13	4

Source: Jardali and Ramet, 1991

TABLE 4

Average casein micelle diameter (micrometres) in camel milks of different origin

Type of milk			**Camel**			**Cow's**
Origin	**Tunisia**	**France**	**Somalia**	**Saudi Arabia**	**the Niger**	**France**
Date of sample:						
month	June	March	October	March	June	Jan-86
year	1987	1989	1989	1990	1990	to Mar-87
Average micelle diameter (micrometres)	325	306	325	280	280	160

Source: Jardali and Ramet, 1991

TABLE 5

Amino acid composition of casein in camel milk and cow's milk

Constituent	**Camel milk**	**Cow's milk**
Aspartic acid	7.28	6. 52
Threonine	4.87	4.42
Serine	5.39	5.75

Glutamic acid	21.26	20.35
Proline	11.62	10.33
Glycine	0.90	2.27
Alanine	1.98	2.80
Valine	5.43	6.48
Cysteine	0.02	0.65
Methionine	2.70	2.51
Isoleucine	6.23	5.54
Leucine	10.89	8.41
Tyrosine	3.84	5.59
Phenylalanine	4.01	4.73
Lysine	6.53	7.33
Histidine	2.44	2.70
Arginine	4.63	3.62

Source: Farah and Ruegg,1989

TABLE 6

Fatty acid composition of camel milk fat (g/100 g)

				Camel				**Cow's**

				milk				milk
Reference	**Yagil 1982**	**Sawaya et al.1984**	**Gnam and Shereha 1986**	**Jardali 1988**	**Farah et al. 1989**	**Abu-Leiha 1987**	**Mohamed 1990**	**Alais 1984**
Fatty acid								
Butyric acid C4	2.10	0.10	0.70	0.97	0.63	-	0.08	3 - 4
Caproic acid C6	0.90	0.20	-	0.10	0.36	-	0.10	2 - 5
Caprylic C8	0.60	0.20	0.20	0.15	0.29	0.10	0.10	1 -1.5
Capric acid C10	1.40	0.20	0.30	0.18	0.87	0.12	0.94	2.00
Lauric acid C12	0.60	0.90	0.10	0.68	0.81	0.77	11.50	3.00
Myristic acid C14	7.30	11.40	10.40	14.38	12.75	10.14	-	11.00
Peutadecanoic acid C15	-	1.70	0.90	1.30	1.23	1.62	31.20	1.50
Palmitic acid C16	29.30	26.70	29.00	35.47	31.75	26.10	8.20	25 - 36
Palmitoleic acid C16:1	-	11.00	9.90	8.83	10.30	10.40	17.30	2.00
Stearic acid C18:1	11.10	11.10	12.00	11.66	12.75	12.20	27.04	12.00
Oleic acid C18:1	38.90	25.50	27.00	20.22	19.54	26.25	1.91	23.00

Linoleic acid C18:2	3.90	3.60	2.60	1.75	3.42	2.94	1.52	2 - 3
Linoleic acid C18:3	-	3.50	-	-	1.41	1.37		-
Arachidic acid C20	-	0.60	-	-	0.96	-		-

Source: Jardali and Ramet, 1991

TABLE 7

Mineral composition of camel milk (mg/100g)

Ca	P	Ma	K	Mg	Reference
127		-		7.7*-10	Khan and Appana, 1965
	96	12*-19	34*-45		
115*-132				12	Yagil and Etzion, 1980
	45*-48	69	156		
106				14-16	Sawaya et al., 1984
	63	27-35	46-60		
131-132				11-15	Gnam and Shereha, 1986
	51-58	38-62	156-210		

107-123				8	Abu-Leiha, 1987
	80-88	36	62		
116				4	Hassan et al., 1987
	71	39	161		
76				-	Mohamed, 1990
	49	33	166		
114					Ellouze and Kamoun, 1989
	87	-	18		
Average:					
Camel milk					
116	67	33	99	11	Jardali and Ramet, 1991
Cow's milk					
125	96	58	140	12	Scher, 1988

Milk from animals with limited access to water

TABLE 8

Vitamin composition of camel milk and cow's milk (micrograms/100 g)

Vitamin	**Sawaya et al.**	**Alais**
	Camel milk	**Cow's milk**
Pantothenic acid	88.00	350.00

Vitamin A (U.I.)	50.00	150.00
Vitamin C	2 370.00	2 000.00
Thiamin	33.00	45.00
Riboflavin	41.00	150.00
Vitamin B6	52.00	35.00
Vitamin B12	0.15	0.30
Niacin	461.00	93.00
Folic acid	0.41	5.90

U.I. = International Unit (0.3 micrograms)

TABLE 9

Relationship between the coagulation and drainage properties of cheese

Coagulation method	**Enzyme**	**Fermentation**
Action mechanism	- specific hydrolysis of K casein - loss of stabilizing effect of fraction K on micelle structure - destabilization in the presence of Ca++ - pH reaction: 6.6	- enrichment of medium in H+ - neutralization of micelle electronegative charge - corresponding micelle demineralization - pH reaction of 6.5 to 4.6

Coagulum composition:	- Ca phosphoparacaseinate - micellar state persists	- casein demineralized - micellar state spoilt or missing (according to pH)
Properties	- mineralized - elastic -not crumbly - impermeable - considerable syneresis needed for mechanical thermal action, chemical action (limited acidification) - necessary for breaking impermeability and utilizing the strength of the gel concentration	- little mineralization - firm - crumbly - permeable-porous - syneresis potential reduced - possible careful application of mechanical and thermal treatments (except centrifugation for fresh cheese)
Whey	- non-acid - demineralized	- acid mineralized
Cheese	- coherent paste - long hardening time - large format - non-deformable - low AW - high pH - suitable for storage	- paste not coherent - short hardening time - small format - deformable - high AW - low pH - not suitable for storage

Source: Ramet, 1981

TABLE 10

Correlation between the coagulation time for camel milk (TFCa) and cow's milk (TFCo)

Type of enzyme coagulant	TFCa/TFCo
Calf rennet	2.2
Mucor miehei protease coagulant	2.3
Chymosin	6.2
Endothia parasitica protease coagulant	17.7
Bovine pepsin	0.2

Source: Ramet, 1990

TABLE 11

Effect of heat on the coagulation and drainage properties of camel milk

Temperature of milk (°c)	34	62	65	75	85
Coagulation					
Flocculation time (mins)	4	4	5	6	6
Gel firmness	+++++	++++	++++	++	+
Gel crumbliness	crumbly				very crumbly
Drainage after 5 h					
pH	6.00	6.65	6.65	6.65	6.65

Gel swelling	+	-	-	-	-
Whey solids (%)	5.40	5.65	5.75	5.89	5.97
Whey fat (%)	0.80	0.80	0.80	0.80	0.80

Source: Ramet, 1987

TABLE 12

Effect of adding sheep's milk to camel milk to make soft cheese

% Sheep's milk	Milk		Cheese			Whey		Yield
	Total dry matter %	Fresh weight %	Dry matter %	Dry weight %	Fresh weight %	Dry matter %	Dry weight %	Dry weight %
100	18.9	22.4	58.0	12.99	77.0	7.6	5.85	68.7
50	14.1	21.8	37.6	8.19	77.2	7.8	6.02	58.1
30	13.3	23.3	32.1	7.47	75.2	7.9	5.01	55.1
0	11.4	11.3	34.2	3.87	89.6	8.4	7.52	33.3

11.7	12.1	32.7	3.96	87.5	8.8	7.70	33.8

Source: Ramet, 1990

TABLE 13

Properties of semi-hard cheese made from camel milk

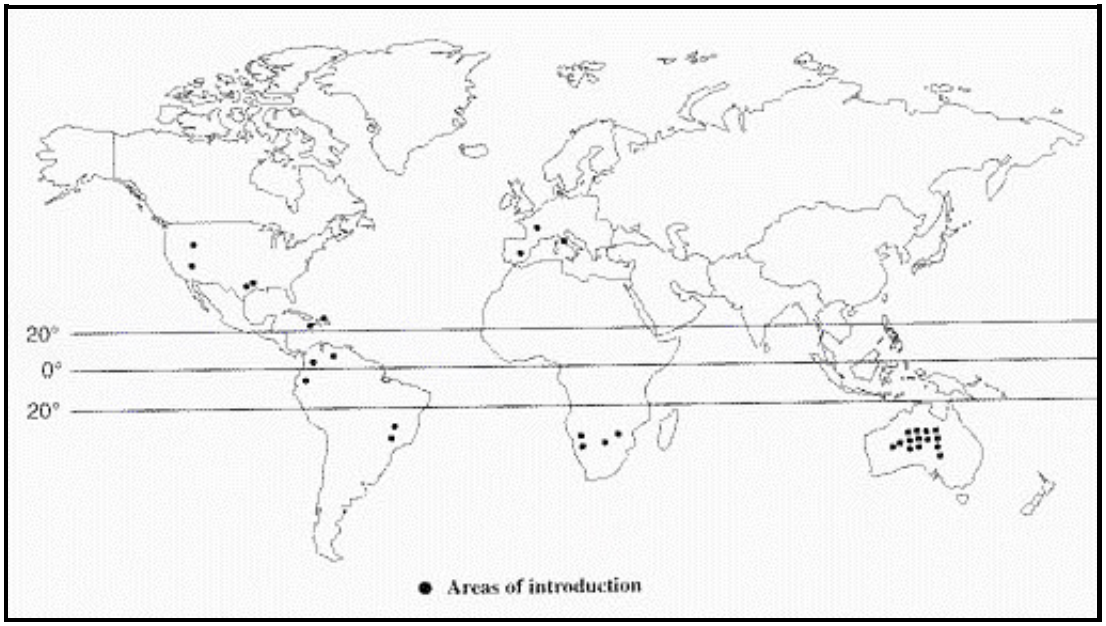
Milk origin		**Camel**	**Cow**
Type of breeding	**Extensive***	**Intensive****	**Intensive***
Milk			
Dry matter (%)	9.46	10.10	12.21
Fat (%)	2.04	2.75	3.20
Coagulation			
pH	6.21	6.61	6.50
Flocculation time (mn)	12.45	7.96	11.50
Cheese			
Dry matter (%)	31.70	45.79	49.96
Fresh yield (%)	6.88	10.74	12.13
Dry yield (%)	3.00	4.60	6.06
Dry matter recovery (%)	31.70	45.79	49.96

Whey			
Dry matter (%)	69.95	65.52	64.53
Fat (%)	13.21	6.29	5.06

Sources: * Ramet, 1987; ** Ramet and Kamoun, 1988

FIGURE 1

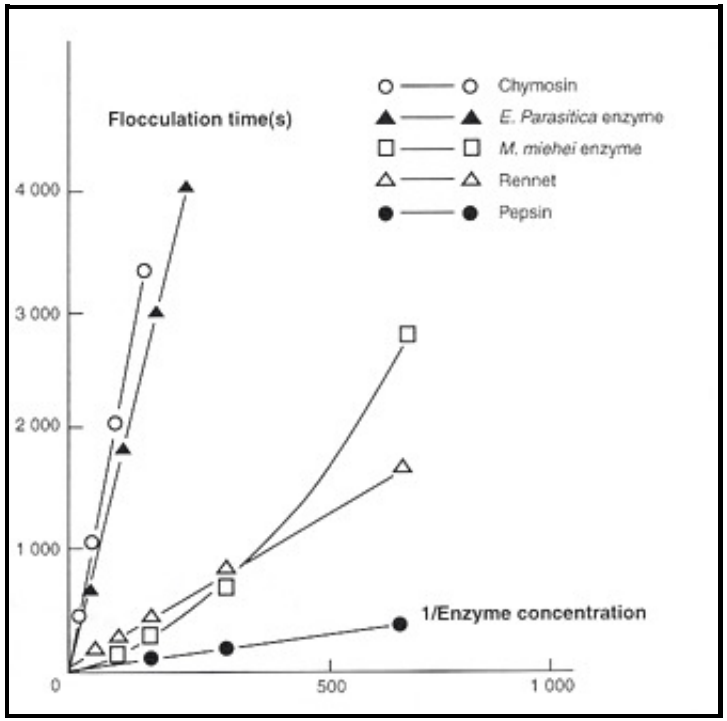
Geographical distribution of the camel (*Camelus dromedarius*)



Source: Wilson, 1984

FIGURE 2

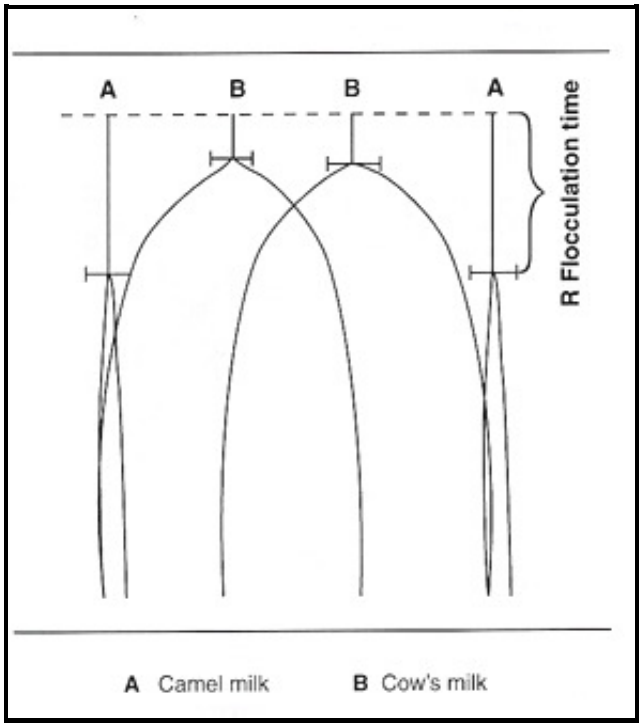
Relationship between flocculation time and the inverse of enzyme concentration for different protease coagulants



Source: Ramet, 1990

FIGURE 3

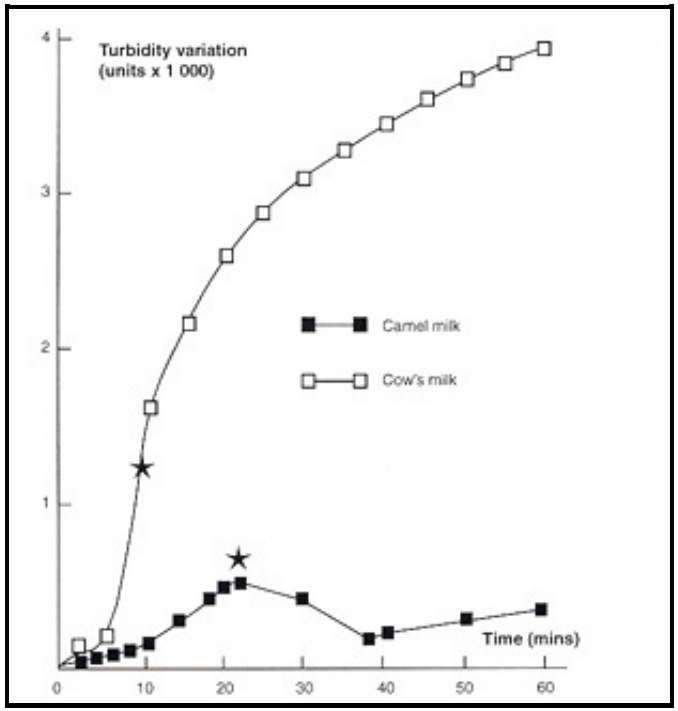
Rheological diagram for flocculation of milk by rennet



Source: Farah and Bachmann, 1987

FIGURE 4

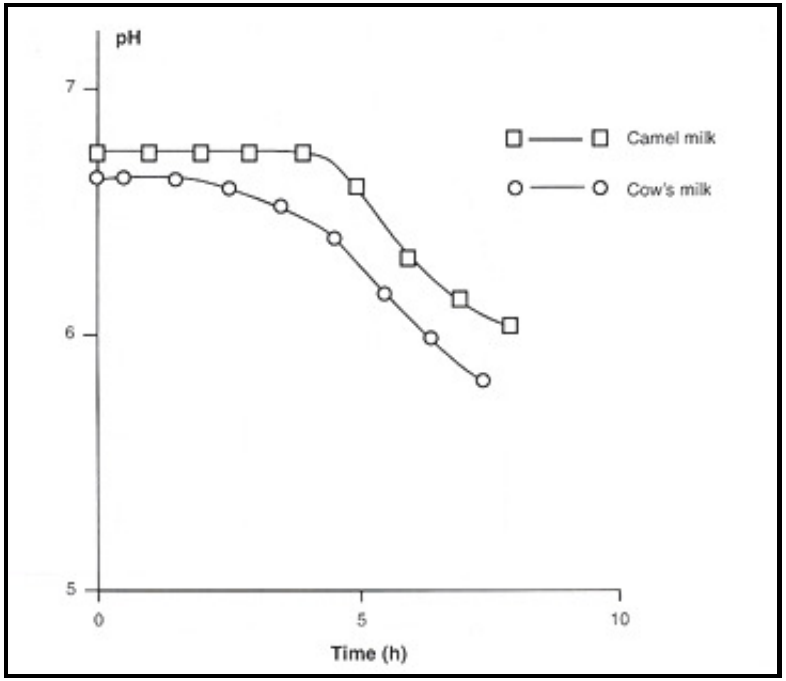
Development of turbidity in camel milk after the addition of rennet



Source: Ramet, 1990

FIGURE 5

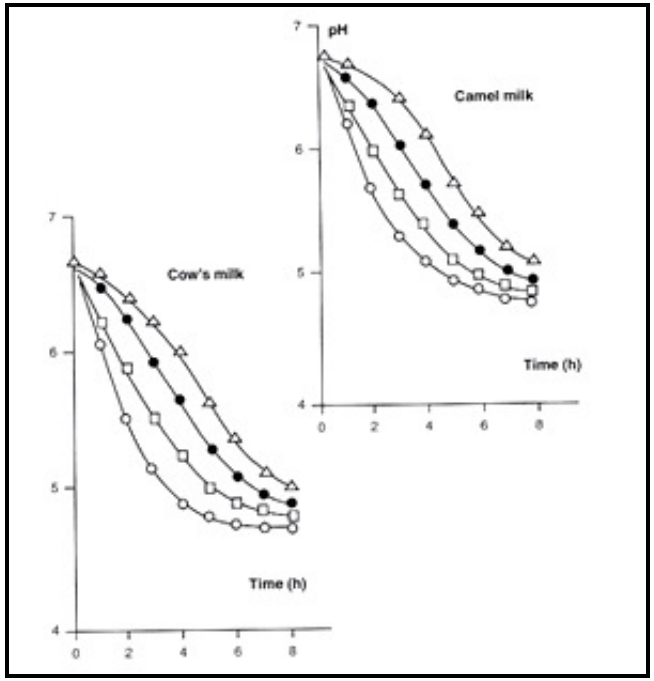
Development of natural acidity in camel milk and cow's milk



Source: Ramet, 1990

FIGURE 6

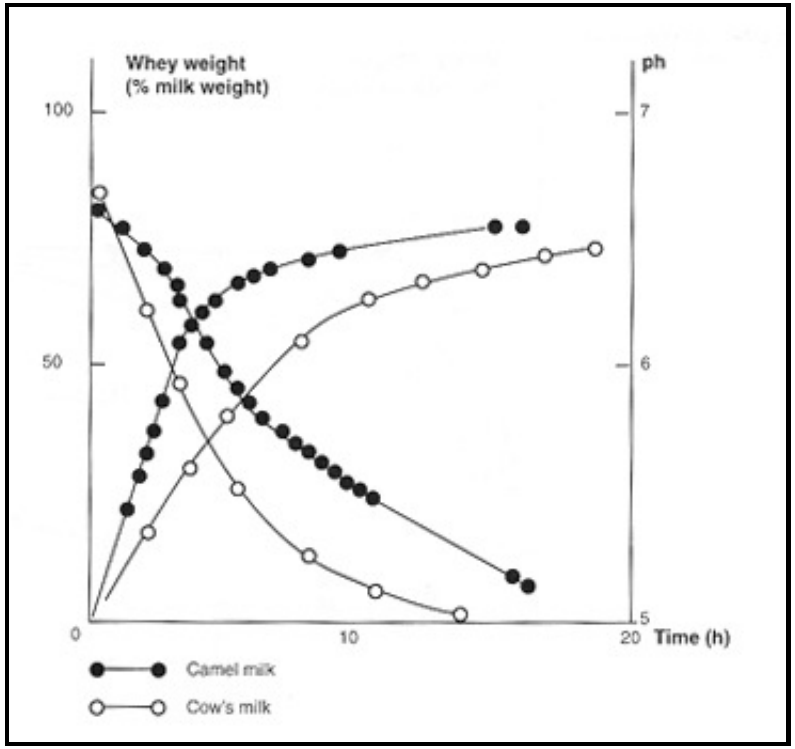
The effect of mesophilic acid bacteria on acidity development in camel milk and cow's milk



Source: amet, 1987

FIGURE 7

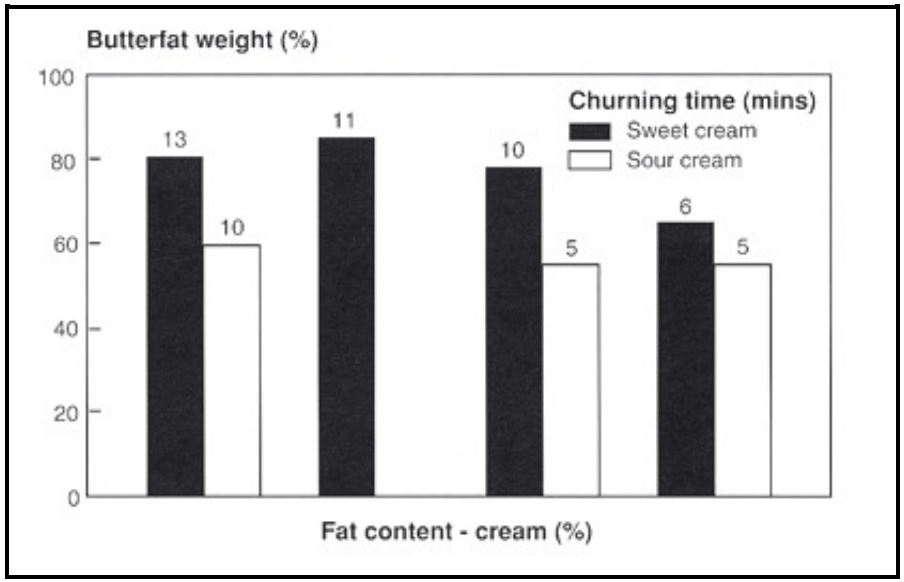
Comparative drainage and acidity curves for acid curds obtained from camel milk and cow's milk



Source: Ramet, 1987

FIGURE 8

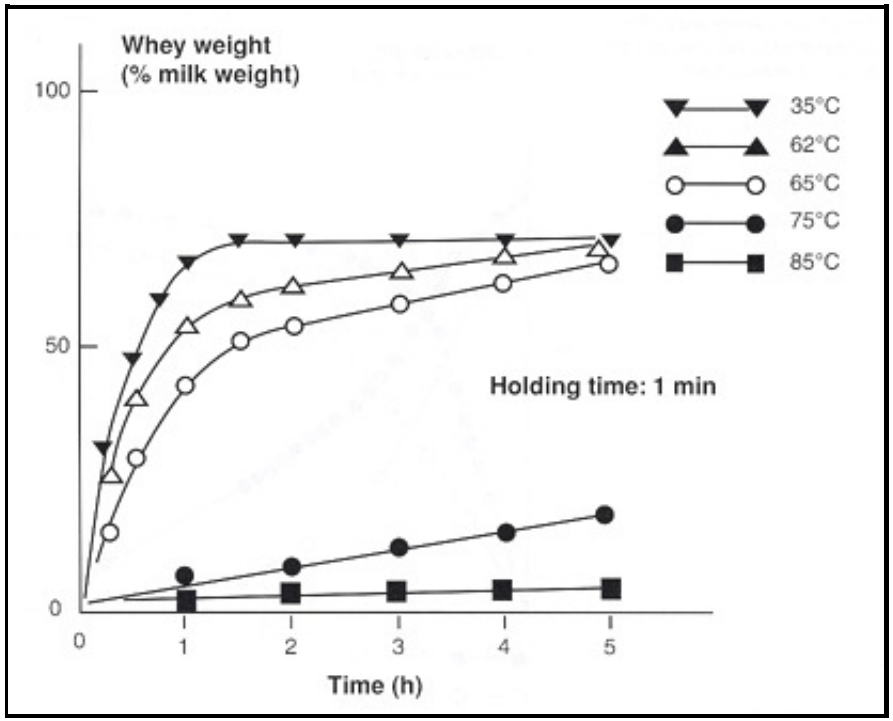
Influence of cream fat content on butterfat yield during churning



Source: Farah, Streiff and Bachmann, 1989

FIGURE 9

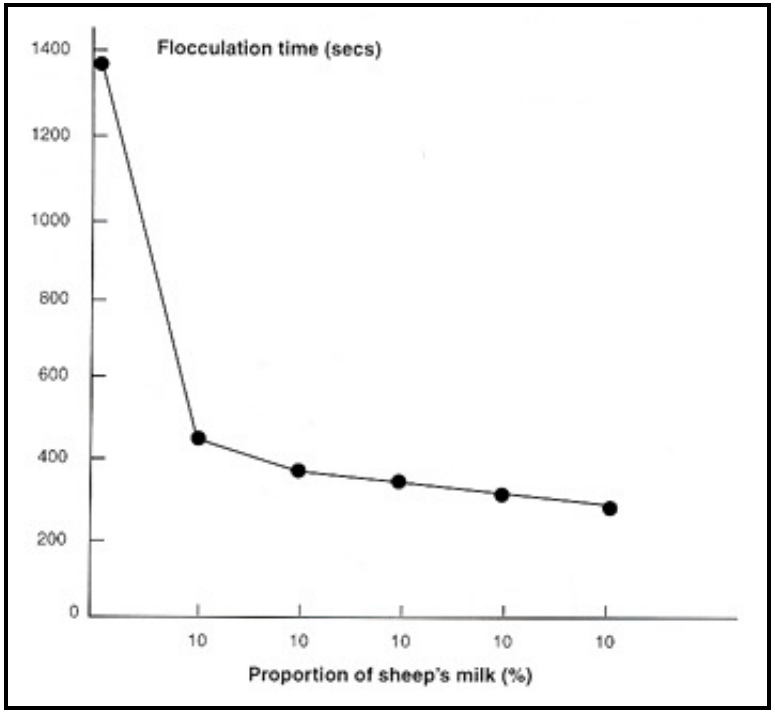
Effect of heating camel milk on the drainage behaviour of whey



Source: Ramet, 1987

FIGURE 10

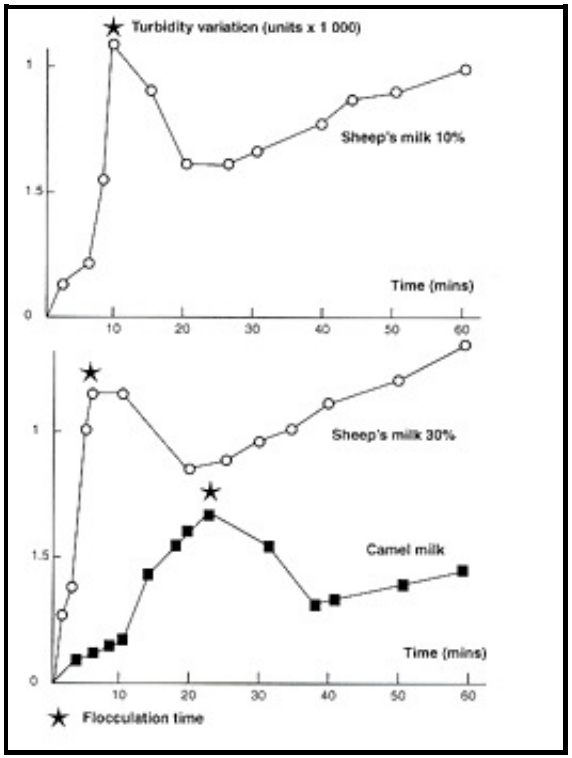
Effect of blending sheep's milk with camel milk on flocculation time



Source: Ramet, 1990

FIGURE 11

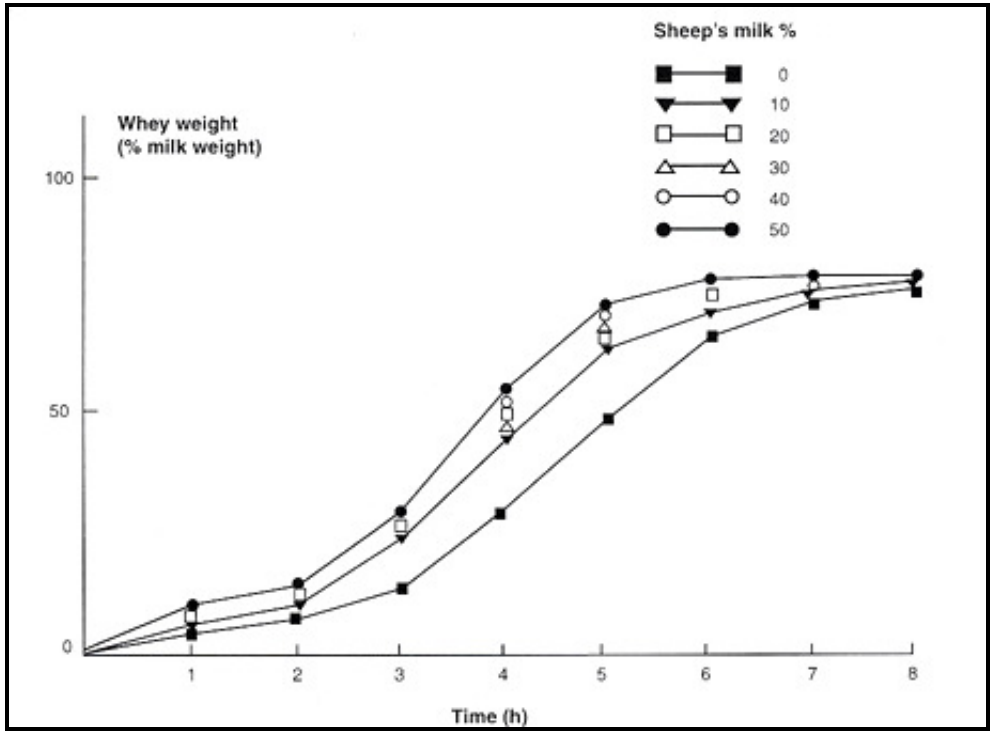
Effect of blending sheep's milk with camel milk on coagulum firmness



Source: Ramet, 1990

FIGURE 12

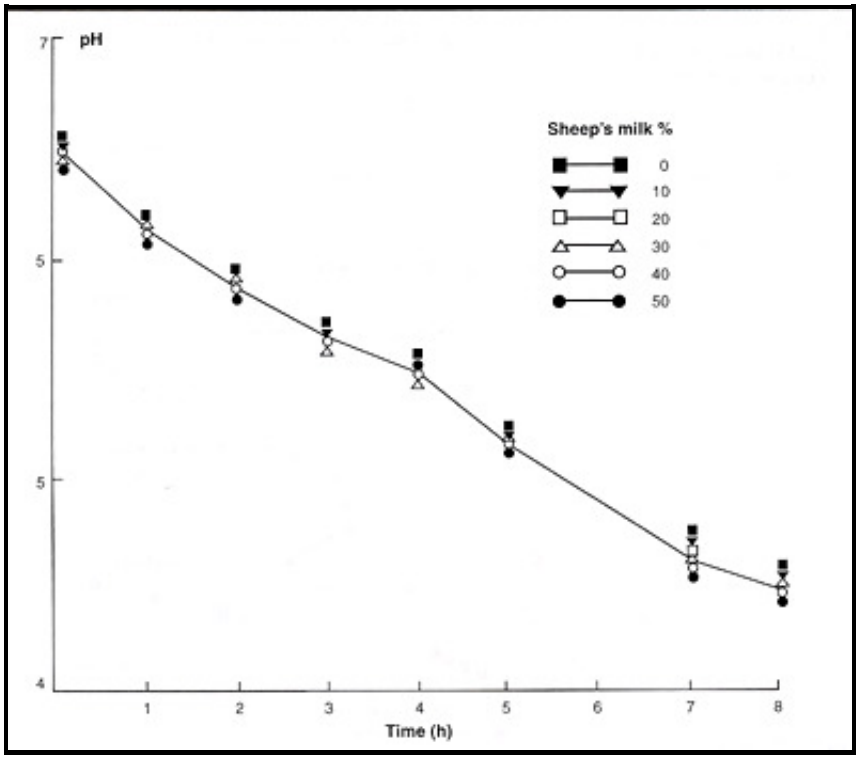
Effect of blending sheep's milk with camel milk on drainage



Source: >Ramet, 1990

FIGURE 13

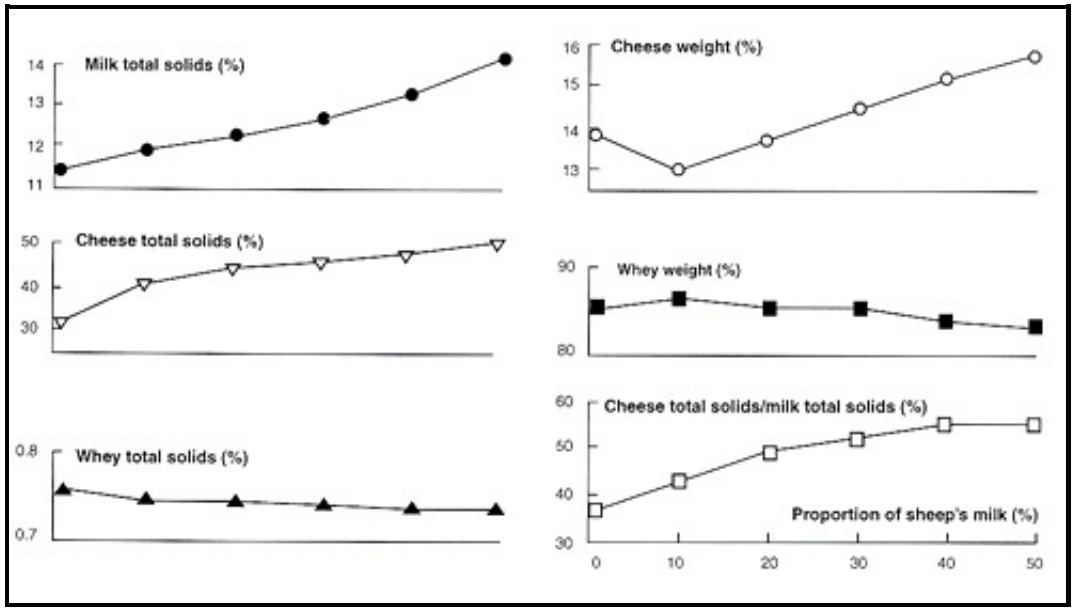
Effect of blending sheep's milk with camel milk on coagulum acidity



Source: Ramet, 1990

FIGURE 14

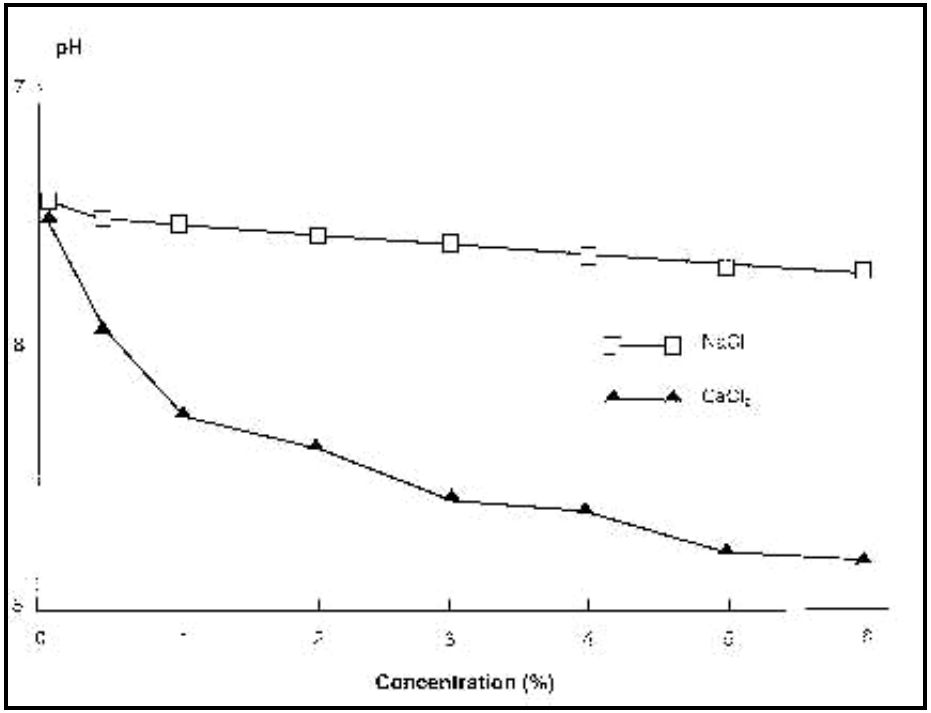
Effect of blending sheep's milk with camel milk on total solids



Source: Ramet, 1990

FIGURE 15

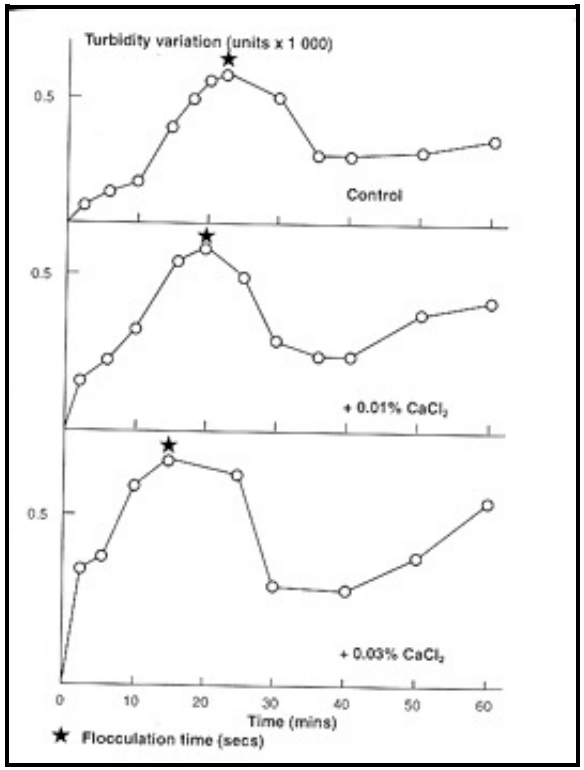
Effect of adding different salts on camel milk pH



Sources: Ramet, 1985b; 1990

FIGURE 16

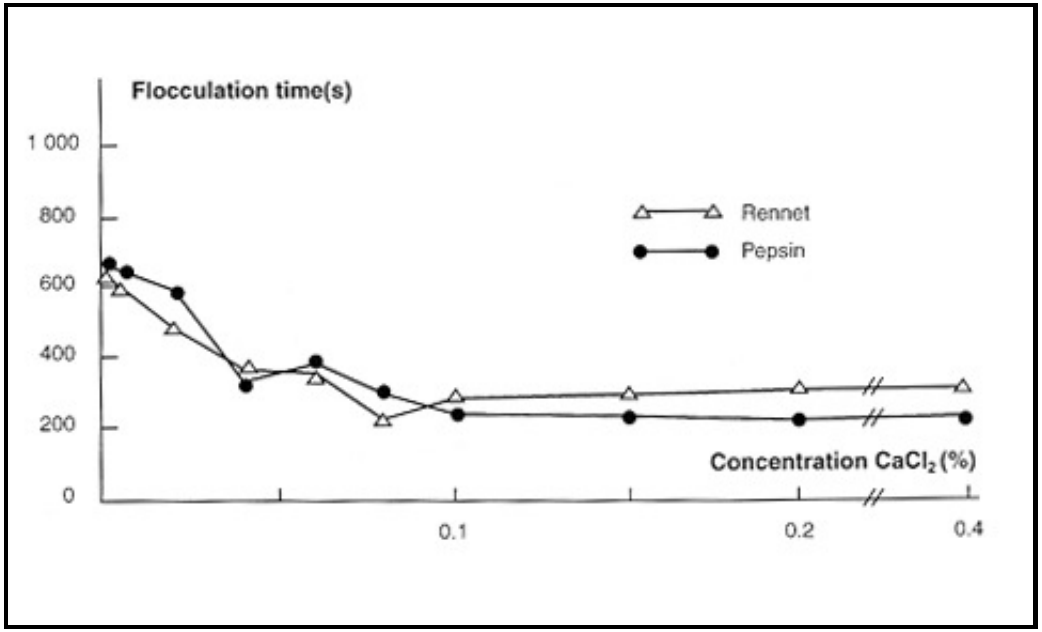
Effect of adding calcium chloride on flocculation time and coagulum firmness



Source: Ramet, 1990

FIGURE 17

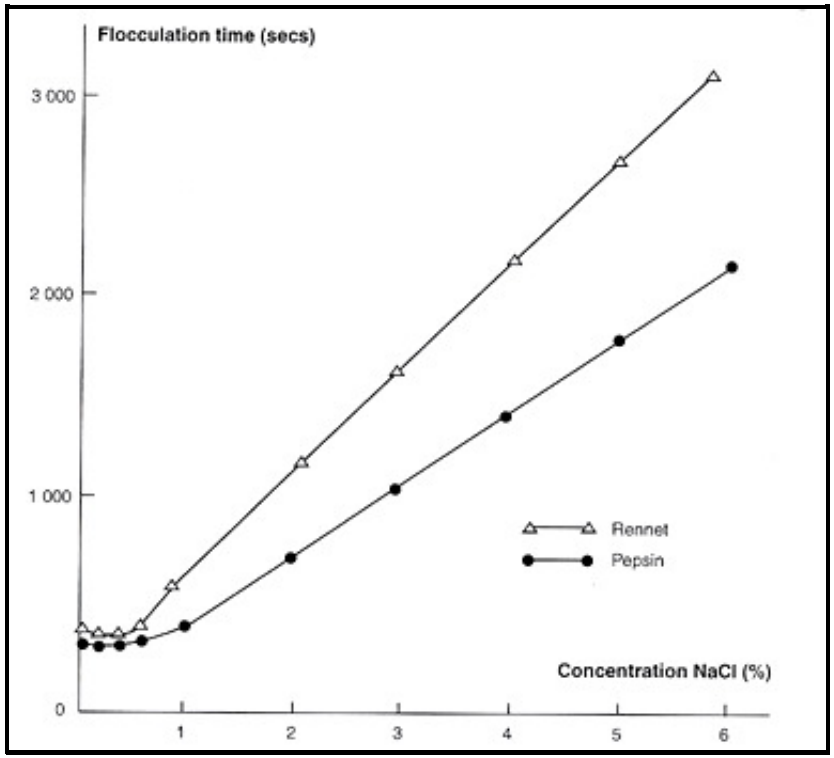
Effect of adding calcium chloride on flocculation time for camel milk



Source: Ramet, 1990

FIGURE 18

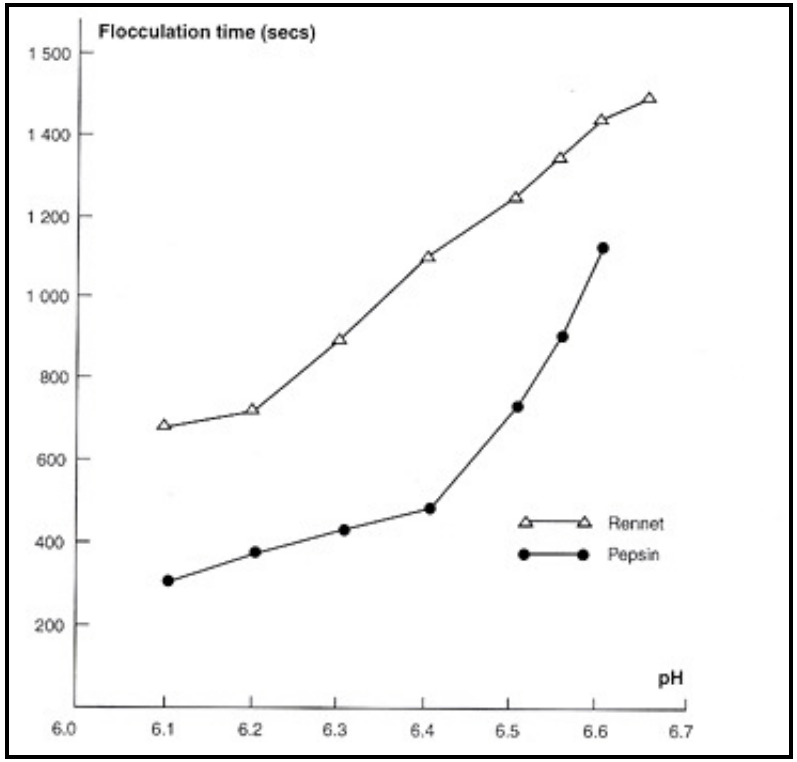
Effect of adding sodium chloride on flocculation time for camel milk



Source: Ramet, 1990

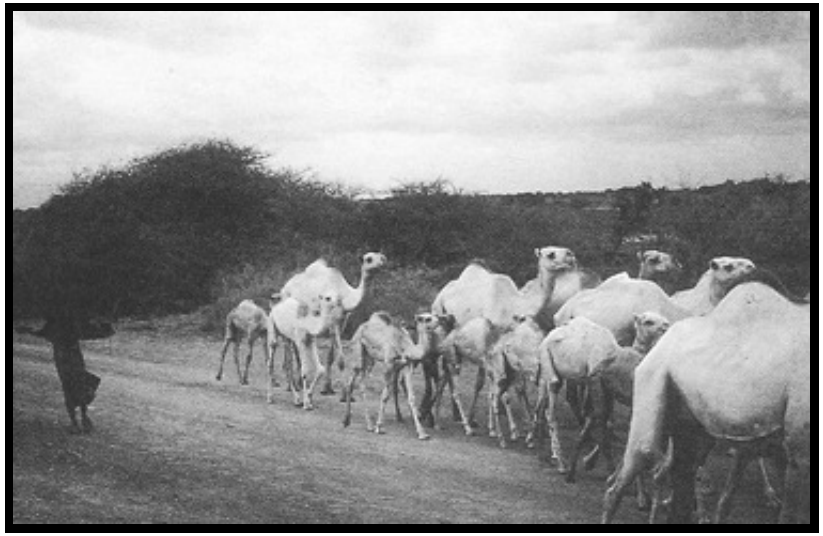
FIGURE 19

Effect of camel milk pH on coagulation activity of calf rennet and bovine pepsin



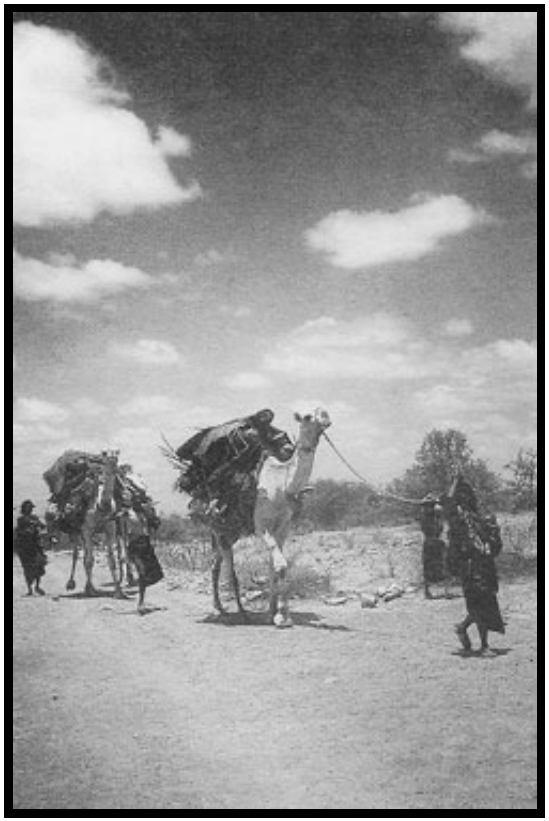
Source: Ramet, 1990

Camels kept under extensive conditions in the Mogadishu region, Somalia (Ramet, 1989a)

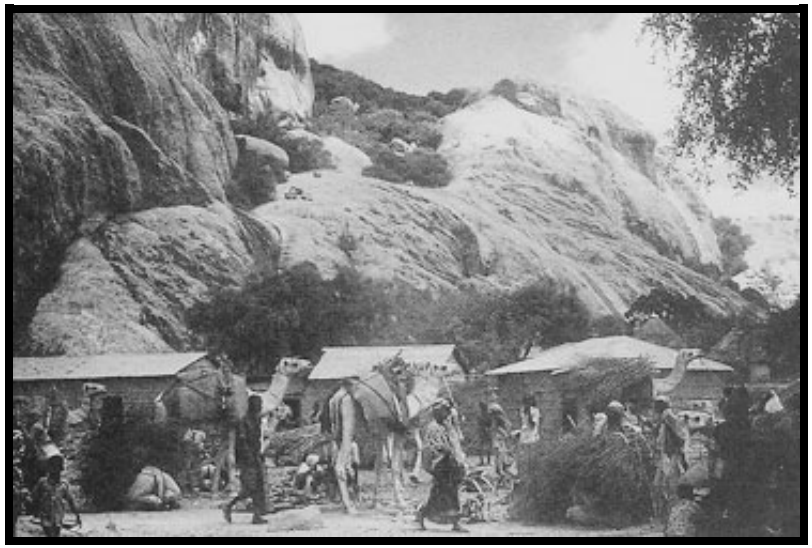


Herd moving along a track in the bush

Camel market



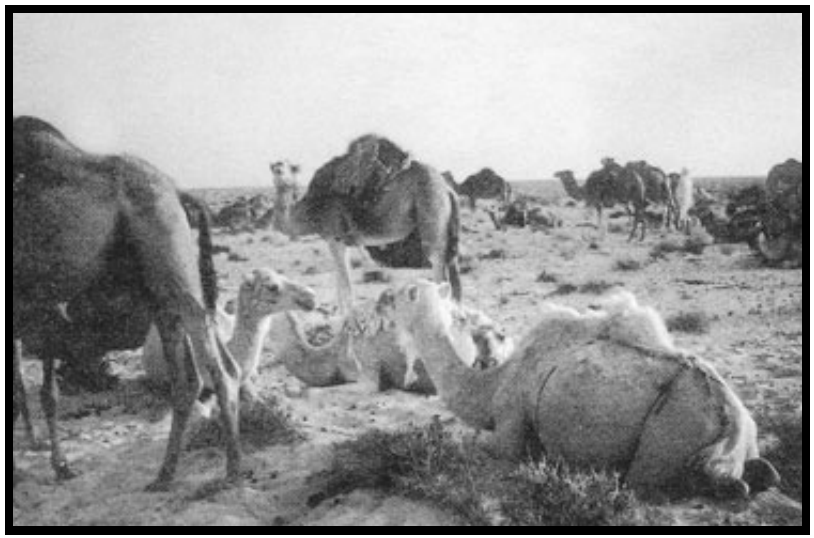
Working camels



Somali nomads

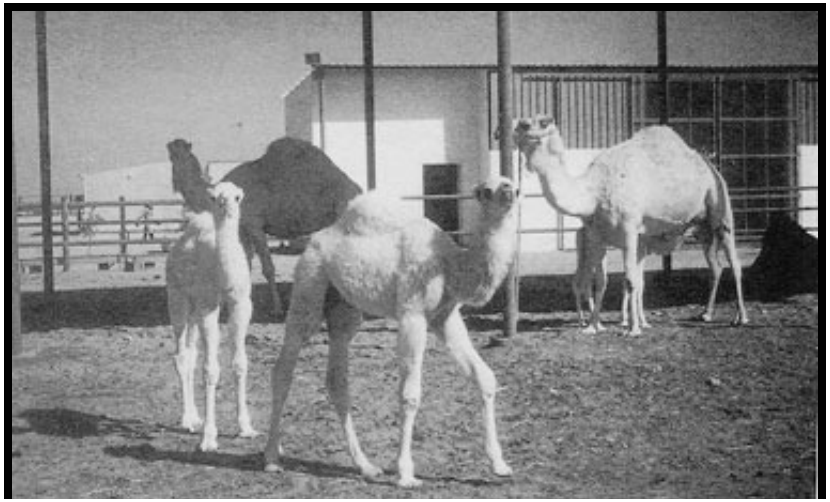
Camels browsing on the plain

Gathering of camels around a well

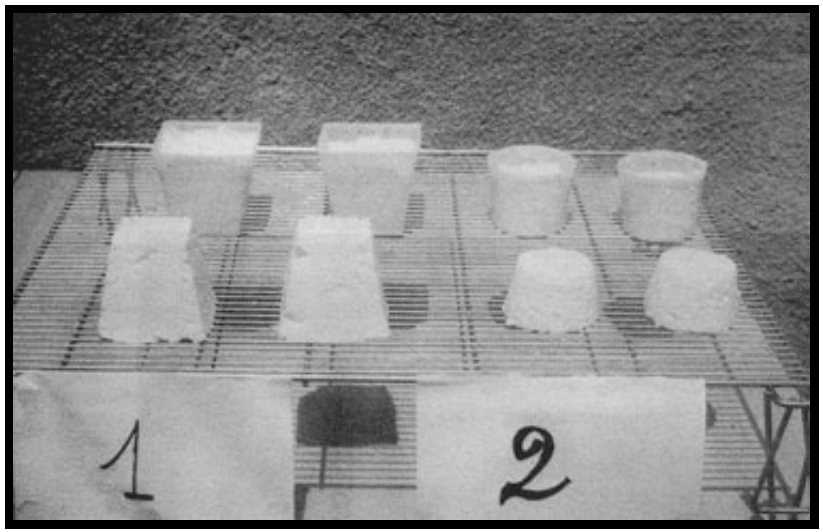


Camels halted for the night

Dairy production under unrestricted housing conditions

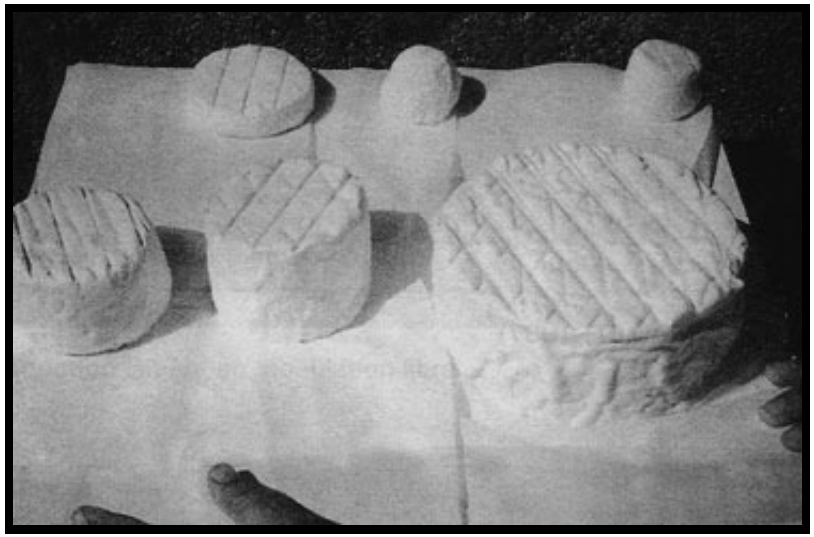


Suckling mothers with their young



Fresh (cottage) cheese (Ramet, 1987)

Semi-hard cheese cured in oil or brine (Ramet, 1987)



Soft cheese treated with the whote mould *Penicillium camembertii* (Ramet, 1990)