LITERATURE REVIEW

The goat and its role as a milk producer in the developing countries

World production of milk is forecast to rise to 665 million tons by 2010, representing an average annual increase of 1.5 percent, compared to an annual average growth rate of 1.0 percent during the 1990s. Milk production is projected to grow in each of the major country groupings (developed, transitional and developing); however, the largest increment is expected in the developing countries. In these countries, the output of milk is projected to rise by 71 million tons to reach 293 million tons. As a consequence, the share of developing countries in world milk production is expected to rise to 44 percent (against 39 percent in the base period and at the start of the 1990s). Conversely, while production in the developed countries and that in transition economies is projected to rise, the relative share of world milk production is expected to decrease in both groups (FAO, 2002).

FAO (2002) also stated that the strongest growth in demand for milk and milk products is anticipated to come from the developing countries, where it is projected to grow at the rate of 2.5 percent per year, broadly comparable with the growth rate during the 1990s. For the countries in transition, little growth (0.9 percent per year) over the 1999 benchmark is projected; however, this would be a substantial improvement over the 1990s, when consumption dropped at an average annual rate of 3.3 percent in this group of countries. In the developed countries, consumption of milk and milk products is also expected to show only limited growth (0.5 percent per year - a similar level to that experienced during the 1990s). Amongst the developing countries, as was the case in the 1990s, consumption of milk and milk products is expected to grow most strongly in Asia, which is projected to account for almost 52 percent of the growth in world demand. Significant growth in demand, 18 million tons, or 18 percent of the projected rise in the world total, is also expected in the Latin America and Caribbean region. Within this region, Brazil and Mexico are anticipated to see the largest increases in consumption. Africa is expected to register the smallest
In many countries in this region this will represent a growth rate slower than that for the population.

Knights and Garcia (1997) reported that in the 'developing' tropics where there are about 95% of the total world's goat populations, this increase demand of milk and milk products could be best made up from goat milk. The goat is well adapted to the tropics; has short generation intervals, high fertility, prolificacy and fecundity; has high heritability for milk production (0.5); has superior digestive efficiency over dairy cattle when fed low quality forages (kg milk yield/100 kg DOM of 67.1 to 145, 86 to 101.5, 73.6 and 71.1 to 91.1 for goats, dairy cattle, dairy buffalo and sheep, respectively) and is a more efficient milk producer under tropical conditions (kg milk yield/kg live weight of 2.8 to 7.1, 2.4 to 3.4, and 4.0 for goats, dairy cattle and dairy buffalo, respectively). Goat milk, owing to its composition, has a greater role to play in future human nutrition and medicine than milk from cattle. Goat farmers would more readily set up or expand goat enterprises because of the lower capital investments required concurrent with lower risks.

This was also supported by the data from FAO (2006) for the 20 highest producing countries of goat milk in the world in 2005 (Table 1), which mostly comes from developing countries and particularly from the tropical area.

According to Galal (2005), developing countries harbour 96% of the world goat population, but only 60% of the breeds. Europe has the heaviest goat breeds with the largest litter size and milk production, while Latin America and the Caribbean scored lowest in all these performance traits. Breed variability was lowest in Europe and highest in Africa. Many goat breeds are not characterized because most goats and breeds are in developing countries, and/or under extensive production systems where characterization becomes more demanding.

Table 1: The twenty highest producing countries of goat milk in the world according to the rank in 2005
<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>Production (Metric Tones)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>India</td>
<td>2,700,000</td>
<td>*</td>
</tr>
<tr>
<td>2.</td>
<td>Bangladesh</td>
<td>1,416,000</td>
<td>F</td>
</tr>
<tr>
<td>3.</td>
<td>Sudan</td>
<td>1,295,000</td>
<td>F</td>
</tr>
<tr>
<td>4.</td>
<td>Pakistan</td>
<td>660,000</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>France</td>
<td>587,000</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Greece</td>
<td>495,000</td>
<td>F</td>
</tr>
<tr>
<td>7.</td>
<td>Spain</td>
<td>465,000</td>
<td>F</td>
</tr>
<tr>
<td>8.</td>
<td>Iran, Islamic Rep.</td>
<td>365,000</td>
<td>F</td>
</tr>
<tr>
<td>9.</td>
<td>Ukraine</td>
<td>290,000</td>
<td>*</td>
</tr>
<tr>
<td>10.</td>
<td>Russian Federation</td>
<td>259,000</td>
<td>*</td>
</tr>
<tr>
<td>11.</td>
<td>China</td>
<td>256,000</td>
<td>F</td>
</tr>
<tr>
<td>12.</td>
<td>Turkey</td>
<td>240,000</td>
<td>F</td>
</tr>
<tr>
<td>13.</td>
<td>Mali</td>
<td>238,590</td>
<td>F</td>
</tr>
<tr>
<td>14.</td>
<td>Indonesia</td>
<td>220,000</td>
<td>F</td>
</tr>
<tr>
<td>15.</td>
<td>Algeria</td>
<td>160,000</td>
<td>F</td>
</tr>
<tr>
<td>16.</td>
<td>Mexico</td>
<td>154,478</td>
<td>F</td>
</tr>
<tr>
<td>17.</td>
<td>Brazil</td>
<td>135,000</td>
<td>F</td>
</tr>
<tr>
<td>18.</td>
<td>Italy</td>
<td>115,000</td>
<td>F</td>
</tr>
<tr>
<td>19.</td>
<td>Mauritania</td>
<td>109,800</td>
<td>F</td>
</tr>
<tr>
<td>20.</td>
<td>Bulgaria</td>
<td>109,320</td>
<td></td>
</tr>
</tbody>
</table>

Source: (FAO, 2006)

Remark:
- * = Unofficial figure
- No symbol = Official figure
- F = FAO estimate

The European Union (EU) has 1.5% (11,730,164 head in the year 2002) of the world goat population. Four countries (Italy, Greece, Spain and France) in the Mediterranean area account for 91% of the EU goat population and 95% of its goat milk production (Moroni et al., 2005b).

2.2 Microbiological characteristics of goat milk
According to compositional differences between the milk from cows, goats, and sheep, the quality standards for the milk from small ruminant animals should be adjusted and evaluated based on the individual milk source (Morgan et al., 2003; Zwijsen et al., 2005). The European Council (EC) (1992), in European Council Directive 92/46/EEC, stated that the TPC and *S. aureus* of small ruminant’s raw milk used for the manufacture of raw-milk products must not exceed 5.7 and 3.3 log cfu/ml, respectively. Those maximum limit standards were similar to milk regulation (Milchverordnung) in Germany which was last amended in 2004 for products ‘made with raw sheep or goat milk’. There was no specific standard for coliforms count within this category, but there was a separate category of milk called “Vorzugsmilch” which was certified for consumption as raw milk. This milk, which was referred to as “certified Grade A milk,” could be sold commercially as a retail product. The number of coliforms in “Vorzugsmilch” must not exceed 2 log cfu/ml (BGBi Teil I Nr. 58 S 2794, 2004). In Indonesia, there was not any specific legal standard for fresh/raw goat milk but there was a standard from Indonesian National Standard for fresh milk (SNI 01-3141-1998) designed, based on cow milk. According to the standard, TPC of fresh milk must not exceed 6.0 log cfu/ml, 1.3 log cfu/ml for coliforms and 2 log cfu/ml for *S. aureus* (BSN, 1998).

Difficulties in managing the sanitary quality of sheep and goat milk derive from a series of factors including the low level of production per head, the milking system, the difficulty involved in machine milking, the conditions under which the herds or flocks are raised, adverse climatic conditions and the spread of production over a wide geographic area (Klinger and Rosenthal, 1997).

The prerequisite to produce hygienic milk and cheese is udder health; therefore, intramammary infections (IMI) are of great importance to milk hygiene in dairy goats (Morni et al., 2005b). Mastitis is one of the most costly diseases in the dairy industry, and, although much information is available concerning mastitis in cows, few studies deal with mastitis in goats. Researchers studying subclinical mastitis in goats agree that IMI caused by coagulase-negative staphylococci (CNS) are the most prevalent. Despite the high prevalence of IMI caused by CNS, CNS were
considered to be minor pathogens. However, IMI caused by CNS was associated with clinical mastitis, changes in milk composition and reduced milk yield; IMI caused by CoNS was also capable of persisting throughout lactation and the dry period (Contreras et al., 1997).

Reports regarding factors affecting small ruminant’s milk quality mainly deal with milk composition as a chemical composition of lipids, phosphatase level, freezing point, natural bacterial inhibitor levels and especially the parameter Somatic Cell Count (SCC) (Haenlein, 2002; Sevi et al., 2004). The relationship of SCC to the microbiological quality of small ruminant’s milk and its expressiveness remains controversial (Zeng and Escobar, 1995). SCC seems to be always influenced by various factors such as stage of lactation, oestrus, parity, time of sampling (before, during or after milking), stress and lambing season (Haenlein, 2002; Sevi et al., 2004). Several authors did not reveal positive interactions of SCC with the presence of bacterial infection or target of microbial tested (Foschino et al., 2002; Delgado-Pertinez et al., 2003, Kyozaire et al., 2005).

Moreover the panel on biological hazards of European Food Safety Authority (EFSA) (2005) has made an opinion on the usefulness of somatic cell counts for the safety of milk and milk-derived products from goats. The panel concluded that due to the high variability of SCC in goat milk, even in healthy animals, SCC cannot be relied on either as a specific indicator for TSE (Transmissible Spongiform Encephalopathy) risk, nor as an indicator of udder health. Three main types of difficulties were noted in the EFSA review:

- The count accuracy is affected by the apocrine nature of milk secretion in goats. Cytoplasmic particles, which derive from the apical part of secretory cells, are normal constituents in goat milk. Certain methods used to count somatic cells cannot distinguish these cytoplasmic particles, similar in size to somatic cells, from real somatic cells, which may lead to false readings. Moreover, the reference microscopy method, which is based on staining procedures, does not give satisfactory results in the majority of laboratories, when used on goat milk.
• Somatic cells that are identified in milk from healthy cows or ewes are mainly macrophages. Less than 30% are other leukocytes. Higher levels of the latter are considered to be indicative of inflammation. On the other hand, leukocytes can reach up to 60% of total cells in normal goat milk. The somatic cell count is therefore difficult to interpret in terms of udder inflammation.

• Non-infectious factors greatly influence the somatic cell count in goats. Physiological normality is dependent on the stage of lactation, age, time of sampling, the oestrus period, feed, stress, breed and the region. Most experts in this field therefore consider that a specific somatic cell count-value derived from one population of goats may describe a normal animal health status in a second population, and indicate mastitis in a third population.

Most of the reports concerning the microbiological characteristics of goat milk were dealt only with investigation on the prevalence of target pathogenic organisms, SPC and microbial quality of the milk (Deinhofer and Pernthaner, 1995; Contreras et al., 1999; Abou-Eleinin et al., 2000; Ndewga et al., 2001; McDougall et al., 2002; Eschino et al., 2002; Contreras et al., 2003; Wakwoya et al., 2006; Leitner et al., 2007; Hall and Rycroft, 2007).

Whereas reports on the evaluation of different factors concerning farm management and milking practices as well as other predisposing factors from goat condition in association with microbial quality and the prevalence of pathogenic bacteria in goat milk were very limited (Zeng and Escobar, 1995; Zeng and Escobar, 1996; Peris et al., 1999; Sanchez et al., 1999; Ameh and Tari, 2000; Zweifel et al., 2005; Kyozaire et al., 2005). Zweifel et al. (2005) reported that from 344 samples of bulk-tank goat milk, the median for Standard Plate Count (SPC) or Total Bacterial Count (TBC) was 4.69 log colony forming units (cfu)/ml. They concluded that farms with a flock size >25 animals, sampled in June, using mechanized milking systems (especially bucket milking without parlor) as well as farms with milk delivery every second or third day,
showed significantly higher SPC levels, whereas the highest probability of a low SPC result was observed during July, in farms with a flock size \(<6\) animals, using hand-milking and daily milk delivery.

It was reported also that the bacteriology of bulk milk samples from different production systems of dairy goat showed that raw milk obtained by the bucket system milking machine had the lowest total bacterial count (16,450 [4.21 log] cfu/ml) compared to that by the pipeline milking machine (36,300 [4.55 log] cfu/ml) or hand-milking (48,000 [4.68 log] cfu/ml) (Kyozaire et al., 2005).

2.3 The pathogenic bacteria in dairy goats

2.3.1 Prevalence of some pathogenic bacteria

The prevalence of some pathogenic bacteria in goat’s milk varies among reports. White and Hinckley (1999) examined goat milk from 2911 udder halves as part of a milk quality-monitoring program over 8 years in Connecticut and Rhode Island, USA. They found that the most prevalent mastitis agents were non-haemolytic \textit{Staphylococcus} spp (38.2%), followed by \textit{S. aureus} (11%), and \textit{Streptococcus} spp (4.1%). Other isolates included \textit{Escherichia coli} (1.6%) and \textit{Pseudomonas} spp (1.2%). Whereas Contreras et al. (1999) investigated bulk tank milk from commercial dairy goats and found that most of the pathogen isolated was \textit{Staphylococcus} spp (95.7%) with \textit{Staphylococcus epidermidis} as the predominant species (66.7%).

Ndewa et al. (2001) reported that bacteria were isolated in 28.7% of the milk samples from small-scale dairy goat farms in Kenya. The most prevalent bacteria was \textit{Staphylococcus} spp. which were 60.3% among all isolates, 37.5% of it were CNS and 22.7% were CPS, followed by \textit{Micrococcus} spp. (17.7%), \textit{Acienobacter} spp. (5%), \textit{Actinomyces} spp. (5%) and \textit{Streptococcus} spp. (1.1%).

Foschino et al. (2002) reported that \textit{E. coli} O157:H7 was found in 1.7% of goat milk samples collected from ten farms in the Bergamo area, Italy. \textit{S. aureus} was found in 43% of samples, whereas CNS were found in 90% of samples, including
Staphylococcus caprae as the coagulase negative species that was the most frequently isolated.

McDougall et al. (2001) also reported that hygienically, goat milk production conditions in Greece and Portugal, under extensive breeding systems had: total bacteria of $3.6 \times 10^7$ and $4 \times 10^7$ cfu/ml; coliforms of $1.8 \times 10^6$ and $2.5 \times 10^6$ cfu/ml; staphylococci coagulase positive and negative of $1.7 \times 10^5$ and $7.6 \times 10^4$ cfu/ml, for Greece and Portugal respectively. For France, using intensive breeding systems, the microbiological quality of the goat milk was: total bacteria $1.08 \times 10^3$ cfu/ml; coliforms $4.50 \times 10^3$ cfu/ml and staphylococci coagulase positive and negative $2.75 \times 10^5$ cfu/ml.

Mottini et al. (2005b) reported that among 305 goats with IMI, 52.3% had unilateral infection, whereas the others had both udder halves infected. Among the bilateral infections, 87% were caused by CNS versus 5% for Staphylococcus aureus and environmental bacteria and 3% by Streptococci. The prevalence of IMI in the left and right half udders were similar with 40.4% and 40.0%, respectively.

Kyozaire et al. (2005) reported that from 270 udder halves, milk samples collected from dairy goat farms with different production systems were infected with bacteria in 31.1% of the samples. The lowest IMI was found amongst goats in the herd under the extensive system (13.3%) compared with 43.3% and 36.7% infection rates under the intensive and semi-intensive production systems, respectively. Staphylococcus intermedius (coagulase positive), Staphylococcus epidermidis and Staphylococcus simulans (both coagulase negative) were the most common cause of IMI with a prevalence of 85.7% of the infected udder halves. The remaining 14.3% of the infection was due to Staphylococcus aureus.

In another study conducted by Leitner et al. (2007), they found that of the 754 udder halves from 377 goats tested, 28.8% were infected with various Staphylococcus species i.e. S. aureus, 9.6%; S. chromogenes, 3.3%; S. epidermidis, 5.9%; S. simulans, 5.5% and S. caprae, 3.3% or Corynebacteria spp., 1.5%.
Whereas Hall and Rycroft (2007) reported that an IMI was found in 53% of the goat's udder halves; the prevalence was 26% on farm A, 39% on farm C and 42% on farm B. CNS were the most common group of organisms, accounting 47% of the infected halves. The number of bacteria in the milk ranged from $1 \times 10^3$ to $1.2 \times 10^5$ CFU/ml. *S. aureus* was found in seven of the samples (13%), most of which yielded between $1 \times 10^4$ and $3 \times 10^4$ CFU/ml; the highest yielded (maximum value) was $1.8 \times 10^5$ CFU/ml. *Corynebacterium* species were present in 16 (31%) of the positive samples and α-haemolytic streptococci were present in three (6%) of them.

### 3.2 Udder infection in dairy goats

Mastitis in sheep and goats is predominantly subclinical (Contreras et al., 1999). CNS are the most prevalent pathogens causing subclinical mastitis in dairy ruminants. Although less pathogenic than *S. aureus*, CNS can also produce persistent subclinical mastitis, significant increase in milk somatic cell count (MSCC), cause clinical mastitis (Deinhofer and Pernthaler, 1995; Ariznabarreta et al., 2002), as well as produce thermostable enterotoxins (Meyrand et al., 1999). Nevertheless, despite the accepted role of these bacteria as major IMI-causing pathogens in small ruminants, the pathogenicity of the different CNS species varies widely (Contreras et al., 2007). The most commonly isolated CNS species in persistent subclinical IMI in goats and sheep are *Staphylococcus epidermidis*, *Staphylococcus caprae*, *Staphylococcus simulans*, *Staphylococcus chromogenes* and *Staphylococcus xylosus* (Contreras et al., 2003; Bergonier et al., 2003).

CNS are the most prevalent organisms detectable on udder skin, inside the streak canal and in mammary glands of dairy goats and sheep. Various CNS species are commonly detected in goat milk and these microorganisms can frequently cause subclinical infections persisting for several months, even through the dry period (Moroni et al., 2005a). In caprine intramammary infection, the CNS are the most prevalent microorganisms (ranging from 25 to 93% of IMI, depending on the study), and are isolated mainly from chronic and subclinical infections (Bergonier et al., 2003).
CNS are contagious pathogens found on the skin of goats and human hands and can easily be transmitted during unhygienic milking procedures (Kalogridou-Sialioudou, 1991). Among the CNS, *Staphylococcus caprae* is the most prevalent species, followed by *S. epidermidis*, *S. xylosus*, *S. chromogenes*, and *S. simulans* (Contreras et al., 1999). Although many of the coagulase negative species noted adapt primarily to non-human hosts, their entry into human foods is not precluded. Once in susceptible foods, their growth may be expected to lead to the production of enterotoxin which can cause staphylococcal food poisoning or food intoxication (Jay et al., 2005).

*S. epidermidis* and *S. caprae* are among the most prevalent causal microorganisms in goats and *S. epidermidis* and *S. simulans* are in ewes. The presence of different CNS species could be attributable to certain practices for controlling mastitis, such as the protocol and type of disinfectant used for teat dipping or dry-off treatments (Contreras et al., 2003). Because novobiocin-sensitive CNS seem to be the most pathogenic, we should consider including this antibiotic in the dry-off treatment procedure (Reinhofer and Pernthaner, 1995), although maximum residue limits for sheep and goat milk have not yet been defined for this antibiotic (Contreras et al., 2007).

Microbiological quality of goat’s milk obtained under different production systems in South Africa was investigated by Kyozaire et al. (2005). They reported that *Staphylococcus intermedius* (coagulase positive), *S. epidermidis* and *S. simulans* (both coagulase negatives) were the most common cause of IMI with a prevalence of 85.7% of the infected udder halves, the remaining 14.3% of the infection was due to *S. aureus*. Wakiwoya et al. (2006) reported that the main bacterial pathogens isolated from goat milk samples were *S. aureus* (12.8%), *Bacillus* spp. (13.8%), *Corynebacterium* (10.9%) and CNS (9.6%). Other bacteria that were also detected included *Streptococcus agalactiae*, *Streptococcus dysgalactiae*, *Klebsiella pneumoniae*, *Enterobacter aerogenes*, *Escherichia coli*, *Pasteurella (Mannheimia) haemolytica* and *Micrococcus* spp.
pneumoniae, Enterobacter aerogenes, Escherichia coli, Pasteurella (Mannheimia) haemolytica and Micrococcus spp.

S. aureus is the most important mastitic pathogen in most herds. Symptoms vary from acute clinical to subclinical mastitis. In particularly severe cases the infection may progress to gangrene. It is characterized by the presence of a watery, odoriferous secretion which may be accompanied by gas bubbles resulting from secondary infection with gas forming organisms (particularly Clostridium spp). Death may be immediate or occur after several days. Some animals will recover and eventually slough away the necrotic tissue (Shearer and Harris, 2003).

2.3.3 Relationship between intramammary infections with some risk factors in dairy goats

Studies have been conducted to investigate the relationship between IMI and some risk factors associated with it in dairy goats to find out the effective way in preventing mastitis at the farm level. Zeng and Escobar (1996) evaluated the effect of breeds and milking methods on SCC, standard plate count and goat milk composition, whereas Bosco et al. (1996) studied the prevalence of subclinical mastitis and the influence of breed, parity, stage of lactation and mammary bacteriological status with the California Mastitis Test (CMT), Coulter Colony Count (CCC), in dairy goats. The relationship between CMT and SCC in dairy goats was investigated by Perrin et al. (1997). Winter and Baumgartner (1999) stated, based on their study results, that CMT can be used as an additional diagnostic tool concerning goat mastitis.

McDougall et al. (2001) have studied the relationship among SCC, CMT, impedance and the bacteriological status of milk with lactation stages in goats and sheep. Shearer and Harris (2003) also stated that the CMT score can be used as a tool for indicating the mastitis status in dairy goats. The CMT reagent reacts with genetic material of somatic cells present in milk to form a gel. In general milk samples from non-infected glands will yield a negative (0), trace, or +1 reaction, score of +2 or +3 are indicative of mastitis.
Characteristics of *Staphylococcus* spp.

The staphylococci were first described by the Scottish surgeon, Sir Alexander Fleming as the cause of a number of pyogenic (pus forming) infections in humans. In 1882, he gave them the name *Staphylococcus* (Greek: *staphyle*, bunch of grapes; *staphys*, a grain or berry), after their appearance under the microscope (Adams and Moss, 2000).

The genus *Staphylococcus* includes over 30 species and those of real and potential interest in foods are about 18 species, out of them only 6 species are coagulase positive (*S. aureus*, *S. aureus* subsp. *anaerobius*, *S. intermedius*, *S. hyicus*, and *S. schleiferi* subsp. *coagulans*). These coagulase positive group bacteria generally produce thermostable nuclease (TNase). Among the coagulase positive species, *S. intermedius* is well known as an enterotoxin producer. Ten of the coagulase negative species have been shown to produce enterotoxins, but they do not produce nuclease, or those that do produce a dermolabile form. The coagulase negative enterotoxigenic strains are not consistent in their production of hemolysins or their fermentation of mannitol (Jay et al., 2005).

Valle et al. (1990) reported that 22% of the 272 CNS isolates originated from healthy goats were enterotoxin positive, and staphylococcal enterotoxin C (SEC) was the most frequently found enterotoxin among the goat isolates. Seven species of the goat isolates produced more than one enterotoxin (*S. caprae*, *S. epidermidis*, *S. haemolyticus*, *S. saprophyticus*, *S. sciuri*, *S. warneri* and *S. xylosus*) and two species produced only one, SEC by *S. chromogenes* and staphylococcal enterotoxin E (SEE) by *S. lentus* (Valle et al., 1990).

Conreras et al. (2007) stated that rather than be a risk for human health that could be caused by some mastitis-causing bacteria, milk is generally heat-treated to minimize this effect. However, in regions where cheese is made from raw milk, controlling clinical and subclinical mastitis becomes a priority. Even when using pasteurized milk, the ability of some bacteria, such as *Staphylococcus aureus*, to produce thermostable toxins, enhances the zoonotic role of these pathogens. Under
European legislation, the control of *S. aureus* is mandatory, such that the marketing of goat and cow milk containing *S. aureus* is highly restricted (Directive 92/46/EEC Council, 1992).

3. **Habitat and distribution**

According to Jay *et al.* (2005), the staphylococcal species are host-adapted with about one-half of the known species inhabiting humans solely (e.g., *Staphylococcus cohnii* subsp. *cohnii*) or humans and other animals (e.g., *S. aureus*). The largest numbers tend to be found near openings to the body surface such as the anterior nares, axillae, and the inguinal and perineal areas where in moist habitats, numbers per square centimeter may reach $10^3 - 10^6$, and in dry habitats, $10 - 10^3$. The two most important sources to foods are nasal carriers and individuals whose hands and farms are afflicted with boils and carbuncles, who are permitted to handle food.

Most domesticated animals harbor *S. aureus*. Staphylococcal mastitis is not unknown among dairy herds, and if milk from infected cows is consumed or used for cheese making, the chances of contracting food intoxication are excellent. There is little doubt that many strains of this organism that cause bovine mastitis are of human origin. However, some are designated as “animal strains” such as *S. lentus* and *S. saprophyticus* which are associated with goats, especially goat milk (Jay *et al.*., 2005).

*Staphylococcus aureus* is highly vulnerable to destruction by heat treatment and to nearly all sanitizing agents. Thus, the presence of this bacterium or its enterotoxins in processed foods or on food processing equipment is generally an indication of poor sanitation. The presence of a large number of *S. aureus* organisms in a food product may indicate poor handling or sanitation; however, it is not sufficient evidence to incriminate the food-products as the cause of food poisoning. The isolated *S. aureus* must be shown to produce enterotoxins. Conversely, small staphylococcal populations at the time of testing may be remnants of large populations that produced enterotoxins in sufficient quantity to cause food poisoning. Therefore, the analyst should consider all possibilities when analyzing a food sample for *S. aureus* (FDA, 2001).
Growth requirements

Staphylococci are typical of other Gram-positive bacteria in having a requirement for certain organic compounds in their nutrition. Amino acids are required as nitrogen sources, and thiamine and nicotinic acid are required among B vitamins. When grown anaerobically, they appear to require uracil. In one minimal aerobic growth and enterotoxin production, monosodium glutamate serves as C, N and energy source. In general, growth occurs over the range 7 – 47.5°C and enterotoxins are produced between 10°C and 46°C, with the optimum between 40°C and 45°C (Jay et al., 2005).

Growth occurs optimally at pH values of 6-7, with minimum and maximum limits of 4.0 and 9.8 – 10.0, respectively. The pH range over which enterotoxin production occurs is narrower with little toxin production below pH 6.0 but, as with growth, precise values will vary with the exact nature of the medium (Adams and Jay et al. (2005) also stated that with respect to $a_w$, the staphylococci are unique in being able to grow at values lower than any other non-halophilic bacteria. Growth has been demonstrated as low as 0.83 under otherwise ideal conditions, although 0.86 is the generally recognized as a minimum $a_w$.

2.5 Dairy food safety issues and public health implications

Consumers are increasingly concerned about the safety of their food and uncertain food production practices. Potential threats to human health related to dairy products and dairy farming include errors in pasteurization, consumption of raw milk products, contamination of milk products by emerging heat-resistant pathogens, emergence of antimicrobial resistance in zoonotic pathogens, chemical adulteration of milk, transmission of zoonotic pathogens to humans through animal contact and foodborne diseases related to dairy animals (Ruegg, 2003).

Ruegg (2003) also reported that the safety of dairy products can be enhanced by adoption of a number of management practices. Sources of microbial
contamination of milk must be minimized by adoption of hygienic standards that can easily be evaluated. There is evidence that microbial contamination of milk can be controlled by the use of standardized best management practices. Mastitis control programs focusing on the hygienic harvest of milk have been widely adopted for at least 50 years. Worldwide, farmers have achieved tremendous success in reducing the incidence of contagious mastitis by adopting the five basic principles of mastitis control: post-milking teat disinfection, universal dry cow antibiotic therapy, appropriate treatment of clinical cases, culling of chronically infected cows and regular milking machine maintenance. Contagious bacteria, such as *S. aureus* and *Streptococcus agalactiae*, are now responsible for less than one-third of all mastitis cases compared with >75% of all cases 20 years ago (Hillerton et al., 1995).

Although numerous studies have documented that foodborne pathogens of public health significance have been isolated from bulk tank milk and are capable of causing disease in humans, people continue to consume raw milk. Many farm families consume raw milk simply because it is a traditional practice and it is less expensive to take milk from the bulk tank than buying pasteurized retail milk, some of them believe that raw milk has a higher nutritional value than pasteurized milk (Oliver et al., 2005).

Oliver et al. (2005) also stated that in addition to direct consumption of contaminated raw milk, introduction of raw milk contaminated with foodborne pathogens into dairy processing plants represents an important risk for the contamination of milk products that could lead to consumers’ exposure to pathogenic bacteria. Although milk pasteurization is regarded as an effective method to eliminate foodborne pathogens, some dairy products do not undergo pasteurization (i.e., specialty cheeses). Furthermore, pathogens such as *Listeria monocytogenes* survive and thrive in post-pasteurization processing environments, thus leading to the recontamination of dairy products. These two significant exposure pathways pose a risk to the consumer from direct exposure to foodborne pathogens in unpasteurized dairy products as well as dairy products which are re-contaminated in the post-pasteurization processing environment. The increasing number of incidences in which
Foodborne pathogens are detected in fluid milk and ready-to-eat dairy products clearly indicates that pasteurization is not the ultimate tool to control milkborne pathogens. It is likely that fecal and foodborne pathogen contamination occurs during the harvesting of raw milk (i.e., milking, collection and storage), and the farm environment likely plays a major role in the presence of foodborne pathogens in bulk raw milk. Reducing the potential for contamination during milk harvesting should result in the reduction of foodborne pathogens in raw milk.

The dairy industry should be concerned about food safety because: (1) bulk tank milk contains several foodborne pathogens that cause human disease, (2) outbreaks of disease in humans have been traced to the consumption of raw milk and have also been traced back to pasteurized milk, (3) raw milk is consumed directly by dairy producers and their families, farm employees and their families, neighbors, etc., (4) raw unpasteurized milk is consumed directly by a much larger segment of the population via consumption of several types of cheeses including ethnic cheeses manufactured from unpasteurized raw milk, (5) entry of foodborne pathogens via contaminated raw milk into dairy food processing plants can lead to a persistence of these pathogens in biofilms and subsequent contamination of processed food products, (6) pasteurization may not destroy all foodborne pathogens in milk and (7) faulty pasteurization will not destroy all foodborne pathogens (Oliver et al., 2005).

Not only must research be conducted to solve complex food safety problems, results of that research must be communicated effectively to producers and consumers. Research and educational efforts identifying potential on-farm risk factors will better enable dairy producers to reduce/prevent foodborne pathogen contamination of dairy products leaving the farm. Identification of on-farm reservoirs should be aided with the implementation of farm-specific pathogen reduction programs. Foodborne pathogens, mastitis, milk quality and dairy food safety are indeed all interrelated (Oliver et al., 2005).