CHAPTER 1

Introduction

1.1 Project theme

Goat milk production

1.2 Project title

Effects of goat phenotype score on milk characteristics and blood parameters of indigenous and improved dairy goats in South Africa.

1.3 Motivation

In Africa, interest in goat *(Capra aegagrus hircus)* farming has increased considerably in the last 10 years in Africa. For example, in Kenya, more than 3000 smallholders are now involved in goat farming and the population of crossbred dairy goats has increased from less than 20,000 in 1991 to over 260,000 in 2004 (Ahuya *et al*., 2009). In Tanzania, there is a rapid increase of dairy goats especially among the resource poor smallholder farmers where these animals contribute substantially to supply milk for children and women. Tanzanian family incomes and nutrition have appreciably improved in areas where dairy goats have been introduced (Kifaro *et al.,* 2009). In Nigeria, caprine milk appears to be more ideal for farmers interested in butter production (Malau-Aduli *et al*., 2002). In Gambia, apart from ceremonial purposes milk for home consumption cannot be ignored (Jaitner *et al.*, 2006). In South Africa, meat breeds such as the South African Boer and Indigenous goats are milked for household consumption (Casey and Van Niekerk, 1988).

Qualities mostly associated with goats include: feed efficiency for meat and milk production, low maintenance cost, robustness and great adaptation to the harsh environmental conditions as well as the inherent suitability for small-scale production systems (Mengistu, 2007). Goats are also a safe investment as compared to crop products usually subjected to seasonal variables like drought, floods, veld fire, acid rains, and acarian attacks. Being a browser, goats (which have the advantage of producing larger

volume of milk than cattle which are grazers) is a much more manageable animal than cows (Berry *et al*., 2002; Richardson, 2009).

Given the relatively lower cost of production characterizing goat farming, more farmers may engage in the milking goat as a possible farming alternative. However, limited information pertaining to nutrient requirements of various breeds of goat in Africa presents a challenge to dairy goat farming. The main challenges are:

i) Selecting an approprate breed or crossbreed to utilize for milk production

ii) Determining nutritional requirements of the lactating dairy goats

iii)Visual appraisal methods or tools to determine the goat milking potentials.

Visual appraisal or Body Condition Scoring (BCS) has been recommended by many authors (Russell, 1983; Nix, 2004; Caldeira *et al*., 2007 and Villaquiran *et al.,* 2007) as an appropriate routine practice in goat farming for the assessment of body energy reserves. Some other authors however (Hady *et al.*, 1994; Halachmi *et al*., 2008; Garcia *et al*., 2008; Rumoza Gwaze *et al*., 2010) have criticized BCS as being subjective, too simple and without accuracy. As apparent, BCS may not be an appropriate tool for the assessment of the goat milking potential. Another indicator needed to be created whereby several factors would be assessed and mathematical relationships developed. Since the factors envisaged for this relationship/assessment included BCS, breed, udder characteristics and age, an empirical term of "phenotype score" was proposed. The focus was the possible use of the "phenotype score" (rather than the BCS alone) as a milk yield predictor. Accuracy in predicting milk yield is critical and hence more appropriate tools needed to be incorporated in the new scoring system. Milk yield and constituents being isotonic to some blood metabolites implied that these blood parameters be incorporated into the evaluation exercise. A study on the interactions beween milk characterisdtics and blood metabolites needed to be done. The purpose was to create and evaluate the "phenotype scoring system" (PTS) as a milk yield predictor.

1.4 Statement of the problem

The continuous and rapid increase of goat populations points to the possibility that these animals might assist in solving some challenges (poverty, joblessness, famines, under/mal nourishment) currently affecting Africa. There are however, some constraints to the development of goat farming, consumption of goat milk and/or production of milk products in Africa. The major constraints are i) the paucity of scientific information on goat reproduction to help improve goat herd management (Amoah,1995) ii) the unfamiliarity of goat milk and goat milk products (Silanikove *et al*., 2008) and iii) the lack of public knowledge of, and appreciation for, the indigenous goat's unique qualities (Devendra, 1980). In Africa, the indigenous goats generally have a poor public image. They are even called "the poor man's cow" (Omondi *et al*., 2008) and often regarded as "backyard animals" of little commercial significance (De Vries, 2008).

There is a need for the African scientists to develop some technical tools that will inform the goat farmers on how to fine-tune decisions in response to the feeding requirements, the productive and reproductive physiology of their herd. Here again, the "Phenotype scoring system" (PTS), which is based on the study of i) milk ii) its constituents iii) the associated blood metabolites and iv) the interactions between milk, blood and the phenotype charactertistics, is expected to provide valuable information to farmers and goat keepers. Knowledge concerning goat nutrition, productive and reproductive physiology is critical in improving dairy goat farming in Africa.

1.5 Aims

The aims of this research were to develop and evaluate firstly the "phenotype scoring system" (a new concept which encompasses BCS, breeds, udder characteristics and age) as a tool for predicting goat milk characteristics; secondly, to evaluate the variation in milk yield and constituents between Indigenous and dairy breeds of goat and thirdly, to determine which one(s) of the currently raised breeds of dairy goats in South Africa can suit to the small scale farming system.

1.6 Objectives

The overall objectives of this study were:

i)To assess the phenotype scoring system (PTS) as a predictor of milk yield and constituents in the Indigenous and the dairy breeds of goat.

ii)To evaluate the suitability (adaptability) of different breeds of goat to the tropical environment, as reflected by the relationship between their phenotype characteristics and some blood metabolites (glucose, blood urea nitrogen, free fatty acids, cholesterol).

iii)To compare milk yield and constituents (lactose, milk protein, milk urea nitrogen and milk fat) of the Indigenous to the dairy does.

1.7 Hypotheses

i)Ho: PTS is a good predictor of milk yield and composition in goats.

ii)Ho: The Indigenous goat is the best suited to the tropical environment

iii)a) Ho: Dairy goats yield more milk than the Indigenous breed.

b) Ho: The Indigenous milk is higher in lactose, milk fat, milk protein and milk urea nitrogen than milk of dairy does.

1.8 Research questions

In view of the hypotheses referred to above the research questions were

i) Can PTS be useful in predicting milk yield and constituents in both the indigenous and the dairy breeds of goat in small scale farming systems?

ii)Which breed of goat raised in South Africa adapts most efficiently to the prevailing African environmental constraints? How will these breeds perform (milk production and BCS) if they were to be raised under the current African small scale farming systems.

iii)Can the indigenous goat milk structure make any contribution as a potential developmental asset in African rural areas?

CHAPTER 2

Critical review of lactation and factors affecting lactation in domesticated goats

2.1. General introduction

The goat world population is estimated at 746 million (FAOSTAT 2010) of which 223 millions are raised in Sub-Saharan Africa with the majority (more than 90%) being raised by smallholder farmers (Rumoza Gwaze *et al*., 2010). In South Africa approximately 7 million goats are raised (Donkin and Ramsay, 2000); and out of nine provinces, three use goats for milk production. Goats are available to Africans, who therefore have the potential to produce their own milk in abundance (quantity and quality).

Domestic goats (*Capra aegagrus hircus*) belong to the kingdom of *animalia*, class of *mammalia*, order of *ruminantia*; family of *bovidae*. The modern goat is a subspecies of goat domesticated from the wild goat of southwest Asia and Eastern Europe between 7000 and 6000BC; it is closely related to sheep; both of them belong to the antelope subfamily of *caprinae*. (Goat-wikipedia) For thousands of years, goats have been used for milk, meat, mohair and skins production over much of the world (Mamabolo, 1998). Female goats are referred to as *does* or *nannies*; intact males as *bucks* or *billies*; their offspring are *kids*. The name "*kid"* also refers to goat meat from younger goats while the term *"chevon"* refers to meat from older goats. As a member of the bovidae family the goat has the ability to convert plant carbohydrates and proteins into available nutrients for human use: milk. Goats can be incorporated into a crop rotation to take advantage of nutrient cycling; they can also be used to control weeds, to harvest crop residues or fight bush encroachment (Goat-wikipedia).

Goats belong to the order of "*ruminantia*", which means that they are members of the group of animals equipped with a "rumen" (the first major compartment of the four-compartment stomach that characterises the cow, the sheep and the goat). The rumen is the "furnace" chamber where microbial fermentation takes place thanks to the millions of

bacteria, protozoa and fungi that inhabit the rumen. These ruminal microbes have the capacity to use the energy-rich plant parts, making them digestible for the host animal. Most of the grasslands and rangeland plants harvested by the ruminants are made of cellulose (the portion of the plant structure that comprises the walls of the plant's cells). Cellulose is very fibrous and indigestible to monogastrics (simple stomached animals). But rumen microbes do produce an enzyme called "*cellulase*" which is the only mammalian secretion capable to breakdown cellulose into cellobiose and then to glucose which is digestible to the microbes and subsequently to the host animals (Rinehart, 2008). Digestion begins when an animal takes a bite from the pasture; as the animal chews, the feed is formed into "bolus" (a packet of food capable of being swallowed). Saliva is excreted, which further aids in swallowing and serves as a pH buffer in the stomach. Once in the rumen, the feed begins to undergo fermentation. Rumen microbes ingest the feed, turning out the end-products which serve as a major source of nutrients for the animal. Some of the principle products formed are ammonia (NH_3) methane (CH_4) carbon dioxide (CO_2) and the volatile fatty acids (VFAs) namely acetate, propionate and butyrate (Church, 1979; Perry, 1980).

Of the three VFAs, acetate is found in large extent circulating in the peripheral blood; in the lactating ruminant. The mammary gland is an important user of acetate for milk fat synthesis. As with acetate, propionate is largely unaltered by the rumen epithelium; it (propionate) is transported via the hepatic portal vein to the liver where it serves as a primary precursor for glucose synthesis which is also synthesized at a lesser contribution from AA, lactate and glycerol. Butyrate, which is found in much smaller quantities than acetate and propionate, is extensively metabolized within the rumen and omasum epithelial cells to form aceto-acetate and beta-hydroxy butyrate; any butyrate reaching the peripheral circulation is either oxidized or contributes to fatty acid synthesis (Sherwood *et al*., 2005). The other end-products resulting from the microbial activity are the large quantities of gas produced – mainly methane (CH_4) and carbon dioxide (CO_2), which must be expelled from the animal through the processes of respiration and eructation on a continuous basis otherwise bloating, ending in death, can occur quickly (NRC, 2007) .

Ruminants require two types of protein in their diet, the protein degraded in the rumen or also the "rumen degradable proteins" (RDP) which are essentially food for rumen bacteria (when microbes die they are passed through to the stomach to the small intestines where they are digested by the animal and absorbed into the animal's bloodstream). The second group of proteins required by the ruminants in the diet is the one that does not undergo rumen degradation, but passes straight to the abomasum or stomach for digestion; this group of proteins is referred to as "rumen undegradable proteins" (RUP). This is the group of proteins that does benefit directly to the animal body. Rumen microbes differ in preferences for nitrogen sources, with ammonia being the most preferred source of many bacteria. Ammonia is absorbed into the animal's system through the rumen wall or is consumed by bacteria to become microbial protein. The microbial protein is then passed through the digestive system to be absorbed in the small intestines (Sherwood *et al*., 2005)

Energy is the single most important dietary component for an animal after water; energy is derived from carbohydrates, fats, proteins and from the animal's body reserves. Energy intake maintains body functions and facilitates growth and development, including reproduction and lactation (Rinehart, 2008).

2.2 Goat milk yield and constituents and some blood metabolites associated with milk production.

2.2.1 Goat milk yield

Goat milk is popular in the nutrition of babies allergic to cow milk and for various therapeutic uses, including the production of up-market cheeses and powdered milk (Silanikove *et al*., 2008). Milk is the liquid nutrient secreted from the mammary gland of mammals for their young (Sherwood *et al*., 2005). It has also been defined as the normal clean and fresh secretion from the mammary epithelial cells of a healthy female mammal excluding week one pre- and post-partum (Pulina, 2002). Milk is secreted from the mammary gland which consists of glandular tissue made of mammary epithelial cells that produce milk and of the excretory ducts that take milk out of the organ. The mammary epithelial cells surround a spherical lumen called milk alveolus; when the cells surrounding the alveoli contract, the hydrostatic pressure in the alveolar lumen increases

and milk is propelled out of the alveoli into milk ducts that empty themselves in a wider chamber called the cistern where milk will be stored before and between lactation ((Sherwood *et al*., 2005).

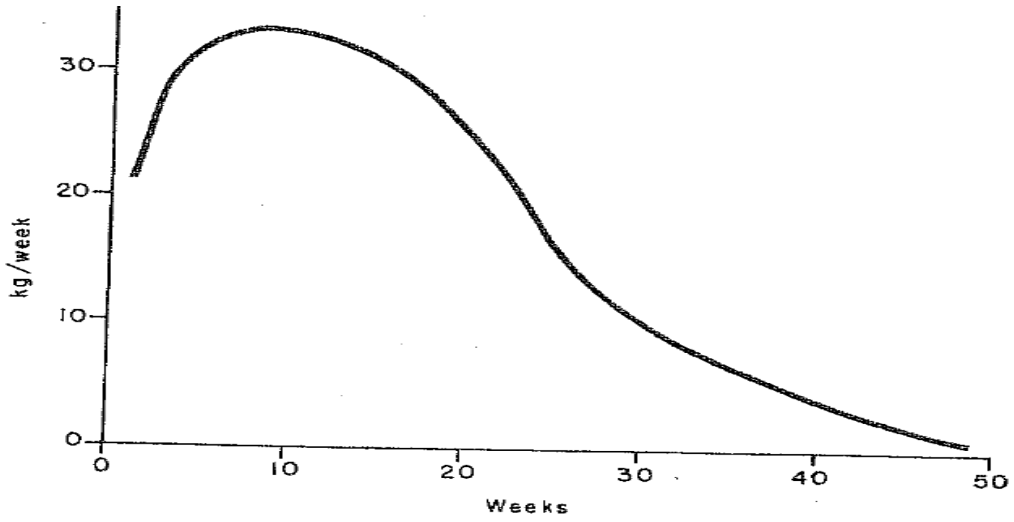
Presumably, the role of hormones is primarily to induce and maintain the activity of synthesizing enzymes in the cells. The rate of uptake of glucose and AA is determined by the rate of synthesis in the mammary epithelial cells, and not by changes in the plasma concentration of metabolic hormones such as insulin, glucagon and growth hormone, which regulate the rate of uptake of these substrates in many other tissues. The mammary cells can take up to 25% of the glucose and up to 60% of the AA that are provided in the blood (Sherwood *et al.*, 2005). Uptake of glucose and AA by the udder is given priority and the udder is allowed to benefit from energy sources stored in other tissues such as adipose and muscle tissues. In dairy cows use of body tissue energy for milk production can account to 82 % (Moe, 1981). Such a redirection of the utilization of nutrients in the body is called "homeorhesis" which is under hormone regulation (Baumann *et al*., 1983; Bell, 1995)

Under homeorhetic regulation lactation uptake of glucose by the mammary gland increases considerably while uptake and utilization of glucose in muscles and adipose tissue is reduced. If insufficient amounts of AA are absorbed from the intestinal tract, muscle proteins will be broken down into AA to be utilized by the mammary epithelial cells. These changes in nutrient partitioning between organs during lactation will occur even when the concentrations of many nutrients in the blood are within the same range as in non-lactating animals (Sherwood *et al.*, 2005).

Earlier studies conducted by Sahlu *et al.* (2007) investigated the effect of diets in milk production and constituents on 249 pastured dairy goats; results showed that milk production and composition were affected by feeding treatment and year. In South Africa, Greyling *et al.* (2004) compared milk production potential of indigenous and Boer goats fed two different feeding systems. It was seen in the intensively maintained groups that feed intake was significantly ($P < 0, 01$) correlated to milk production irrespective of the breed. Raats (1988), who worked on the effect of supplementation on milk yield in Boer goats and found that milk production is affected by level of nutrition, reported similar results. However, reports on the effect of level of nutrition on milk constituents

are sometimes contradictory. Oltner *et al.* (1983) found slight changes in yield according to level of nutrition and protein/energy ratio, but no obvious patterns emerged.

To conclude, milk yield is subject to much variation i) both between and within breeds (Makun *et al*., 2008; Richardson, 2009) ii) with age, stage of lactation, parity and season (Pulina, 2002). A classic lactation curve of does reported by French (1970) is represented in Graph 1.1.



Graph 1.1: Lactation curve of does during one year (French, 1970).

2.2.2. Goat milk constituents

Milk constituents are principally synthesized by the secretory cells of the mammary gland from the precursors adsorbed from blood circulation. These precursors derive directly or indirectly from nutrients in the diets (Pulina, 2002). Goat milk can successfully replace cow milk, especially for people who are allergic to cow milk; it is nearest to human milk in its content of fat and protein (see Table 1.1 and Table 1.2, next page) and serves as a good dietary source of minerals which makes it a complete food for neonates (Bawala *et al*., 2006). Goat milk is a very tasty, very delicious and very nutritious product with a slightly sweet and sometimes salty undertone.

Table 1.1: Average composition of milk from different mammals by percentage

Species	Water	Fat	Proteins	Lactose
Goat	87.00	4.25	3.52	4.27
Cow	87.20	3.70	3.50	4.90
Ewe	80.71	7.90	4.81	4.81
Human	87.43	3.75	1.63	6.98

(Source: Webb and Johnson, 1965)

Table 1.2: Average vitamin content of goat, cow and human milk

Vitamins	Cow	Goat	Human
A	1560.0	2074.0	1898.0
D	---	23.7	22.0
B1	0.44	0.40	0.16
B2	1.75	1.84	0.36
Nicotinic acid	0.94	1.87	1.47
B12	0.0043	0.0006	0.0003
C	21.1	15.0	43.0

(Source: Prakash and Jenness, 1968)

Cow's milk is the most commonly used by humans, but goats milk is more valuable than cow's milk in terms of DM (dry matter), milk fat, milk proteins, lactose or even minerals like Ca, P, Cu, Mn, and K or vitamins like Vit. B_3 and Vit. A (Pruzs and Selegovska, 2004). Goat milk is richer in vitamins and minerals; as such, it is particularly appropriate for the diet of elderly, the sick and the children (Dario *et al.,* 2008). Goat milk is more digestible than cow's milk, because of its protein make-up: its low levels of the protein α s1-casein – which is responsible for allergy to certain persons – than cow's milk. Some goats do even naturally produce very little α s1-casein. Goat milk can be drunk fresh; pasteurization is however, recommended to reduce naturally occurring bacteria such as *staphylococcus aureus* and *eischerichia coli* (Clark, 2007)

The gross biochemical composition of goat milk varies markedly with different breeds, physiological and environmental factors; however, the composition below (Sherwood *et al.*, 2005) is generally accepted as a standard:

- Carbohydrates (lactose) 4.5%
- Milk Fat 4.1%
- Proteins 3.6%
- Calories (kcal) 69 %
- Minerals 0,7% and
- Water 87%.

Lactose, milk fat, milk proteins and water are the main components of milk.

2.2.2.1 Lactose content of goat milk

Lactose is the milk sugar or the carbohydrate nutrient in milk (Richardson, 2009). Lactose is synthesized from glucose extracted from blood by lactose synthetase enzyme activity of the Golgi apparatus in the mammary gland's epithelial cells. Lactose, a non-permeable disaccharide which consists of two molecules (one glucose and one galactose) connected by a ß-1-4 glycoside bond is too large to diffuse out of the Golgi apparatus or out of the secretory vesicles; so it draws water by osmosis into the Golgi from the cytoplasm (Zubay, 1986). When milk synthesis starts, the mammary epithelial cells under the influence of prolactin induces the synthesis of α-lactalbumin which then binds to the regulatory unit of lactose synthetase which in turn will link UDP-galactose to glucose, forming lactose; between 50 and 60 % of the glucose taken up from plasma is used to form lactose (Sherwood *et al.*, 2005).

Lactating ruminants often exhibit a glucose deficiency when milk production is high, because the udder then uses between 70 and 80% of the total available glucose. Bauman *et al*. (1980), Bergman (1983) and Weekes (1991) indicated that 85 to 90% of the total glucose produced in the ruminant was taken up for lactose synthesis during lactation; a finding later supported by Chang *et al.* (1996) who showed that the uptake of glucose by the mammary gland of the dairy goat amounted to 14.6 mg/dl of the blood perfusing the udder. In earlier studies Hossaini-hilali *et al.* (1993) investigated fluid

balance secretion in fed and feed-deprived black Moroccan goats; results showed that plasma glucose concentration was higher in lactating than in non-lactating goats; this was later verified by Pambu (1997) who worked on Indigenous goats in South Africa and found a difference in blood glucose concentrations between the lactating and non-lactating goats. This was also the opinion of Hussain *et al.* (1996) who compared the underfed goats to the well fed group and explained that, during lactation, there was an increased glucose requirement for lactose synthesis; a finding earlier supported by Radloff *et al.* (1966) who reported a positive correlation between blood glucose concentration and lactose and also milk protein concentrations.

Many authors (Faulkner *et al*., 1979; Sano *et al*., 1985 and Bell, 1995) have mentioned that blood glucose is the only precursor of milk lactose and therefore, glucose uptake by the udder is important for milk secretion. It has been indeed demonstrated that anything that alters blood glucose concentration: cold stress (Faulkner *et al.,* 1979), heat stress (Sano *et al.,* 1985), administration of insulin and intra-ruminal infusion of acetate (Rook *et al*., 1966) does also affect lactose and, as a consequence, milk yield. Glucose is definitely the only precursor to lactose synthesis and lactose is the most important osmotic solute in milk (Bell, 1995). Pulina (2002) expressed this view by saying that milk is osmotic with blood plasma while lactose is the main osmolar component of milk.

In short, lactose importance in determining milk volume is such that, if, secretion of lactose ceases, milk volume will be greatly reduced (Pulina, 2002). Glucose plays an important role in the secretion of milk (approximately 85% of the lactose is synthesized from glucose); if plasma concentration of glucose falls below a certain level, lactose secretion will cease; and milk secretion will be impaired; for this reason lactose may stand as an indirect indicator of the energy status (Bed *et al.,* 2007). Lactose concentration is relatively constant (4.8% on average) in milk; lactose and triglycerides are primarily utilized as energy sources (Sherwood *et al.,* 2005).

2.2.2.2. Protein content of goat milk

Milk proteins with the exception of serum albumin and immuno-globulins are synthesized from the amino acids (AA) extracted from blood in the rough of endoplasmic reticulum of the epithelial cells and are transported to the Golgi apparatus where some are

modified before they are transferred to the secretory cells. Those AA derive from the post-ruminal digestion of microbial protein and the undegradable rumen protein (RUP) from hepatic transamination reactions, and when ration protein concentration is scarce, from the mobilization of tissue proteins (Pulina, 2002). Goat milk contains a similar AA profile to cow milk except for a lower concentration of cysteine and a higher concentration in taurine; glycine and glutamic acids are the major goat milk free AA. Taurine more specifically is involved in bile salt formation; it regulates blood pressure and alleviates other cardio-vascular ailments in adults (Silanikove, 2008). Milk proteins composition from the lowest to the highest electrophoretic mobility is:

- α-casein, β-casein, K-casein, γ1-casein, β-lactoglobulin, α-lactalbumin, γ2-casein and γ3-casein)
- Minor whey proteins (Lactoferrin. Serun albumin, Immunoglobulin G) (Albenzio *et al.,* 2009).

Although the principal proteins in goat milk are the same as in milk from other species, the relative proportion of the four major caseins in caprine milk varies widely between individual animals (Albenzio *et al*., 2009). Serum albumin and immunoglobulins, which are very high in colostrum and increase during mammary gland inflammation and during uterus involution, are not synthesized in the mammary gland; they pass directly from blood into milk ((Sherwood *et al*., 2005). The lactating mammary gland of goats has the ability to utilize AA of peptide origin for milk synthesis (Backwell *et al*., 1994). Removal of AA supply for milk synthesis at the level of the mammary gland is a function of AA supply (concentration and blood flow) and the affinity of the udder for individual AA. Blood flow and AA transport activity appear to act in concert to allow the udder to cope with fluctuations in AA concentration and to ensure that the uptake of AA is adequate to meet the demands for milk proteins synthesis (Mabjeesh *et al.*, 2002).

The composition of total protein in milk depends on the energy/protein ratio in the diet, on its crude protein concentration and on the use of the rumen-protected protein (Pulina, 2002); during early lactation the ability of the animal to produce milk frequently exceeds her ability to consume sufficient energy to meet requirement for milk production. The animal must rely heavily on body stores of energy and protein during this period; this

breakdown of muscle proteins to provide AA for milk protein is a mechanism of normal metabolic adaptation (Boots *et al.*, 1978). Milk protein is therefore positively correlated to the energy content of the ration, particularly when the additional energy comes from soluble carbohydrates.

Generally dietary crude protein (CP) concentration affects milk yield and consequently results in protein yield increases. The reverse is also true, when animals are fed poor quality forage (or a diet deficient in CP), milk proteins content decreases. A negative relationship between dietary CP and milk proteins percentage can also be an indicator of excess RUP in diets. Excessive RUP has been associated with decreases in microbial protein synthesis and AA flow to the small intestine. On the other hand, feeding excessive degradable CP, such as urea, can reduce milk proteins content. To optimize the dietary utilization of nitrogen, the diet should be balanced for energy and protein both for quantity and for rumen kinetics (Sherwood *et al.*, 2005).

2.2.2.3 Lipid content of goat milk

One of the most interesting aspects of milk from small ruminants concerns the nature of its fat. The higher proportion of small milk fat globules present in goat milk as compared to cow milk does contribute to the tendency of goat milk to be more easily digested (Silanikove, 2008). Cow milk fat globules tend to separate to surface; in contrast, goat milk globules are much smaller and remain suspended in solution, thereby reducing the need for homogenization (Clark, 2007). Milk from sheep and goats has a fat rich in medium-chain triglycerides (MCT) made up of fatty acids (FA) with a carbon chain composed of 6 to 10 atoms of carbon; these are caproic (C6:0), caprylic (C8:0) and capric (C10:0) fatty acids, also called “goat fatty acids” (Sanz-Sampelayo *et al*., 2006) of which capric (C10:0) fatty acid in particular is responsible for the characteristic goaty odour of goat milk and is therefore useful to distinguish goat’s milk with different FFA composition (Pereira *et al.,* 2008).

The so called “Goat fatty acids” are bound to glycerol and together they make up to one-fourth to one-fifth of all the FA found in the goat milk (Astrup *et al*., 1985). Milk fat is composed primarily of microscopic membrane-covered droplets of triglycerides, which are formed by the linking of glycerol and fatty acids synthesized at

the outer surface of the smooth endoplasmic reticulum. The major storage form of lipid in milk is triglycerides; it represents between 97 and 98% of milk fat; the rest are phospholipids and cholesterol which form part of the membrane around the fat droplets (Pulina, 2002).The hydrolysis of milk fat globule triglycerides into FFA is carried out by lipoprotein lipase, an enzyme that also plays a key role in regulating the level of plasma lipoproteins in adipose and muscular tissues as well as in other body components like liver, heart and nervous system, including the mammary gland (Badaoui *et al.*, 2007). During lactation the enzyme lipoprotein lipase in the capillary walls hydrolyzes triglycerides (Sherwood *et al*., 2005). Milk fat is synthesized either from FA from blood (60%) or by *de novo* synthesis in the mammary gland (40%) (Chilliard *et al*., 2000). Short chain FA (C6–C10) is built *de novo* in the mammary epithelial cells from acetic acid deriving from rumen fermentation and ß-hydroxybutyrate formed in the rumen wall (Sherwood *et al*., 2005). Milk FA of chain length C-18 and above are from blood lipids which originated from fat intake in the diet and from mobilization of body fat. Medium chains (C-16) derive either from dietary lipids or from *de novo* mammary synthesis (Pulina *et al.,* 2005).

In comparison with cow milk, goat milk is much higher in medium-chain fatty acids (C8: caprylic acid and more markedly C10: capric acid) (Chilliard *et al*., 2003). Grasses contain mostly α-linolenic acid (C18:3) whereas grain contains primarily linoleic (C18:2) and oleic acid (C18:1). These unsaturated fatty acids are also known as “essential fatty acids”; they have been shown to exert positive effects on human health; oleic and linolenic acid more particularly both have a cardioprotective effect through a direct vascular anti-allergenic action (Chilliard *et al*., 2003). Milk fat content is high after parturition and then decreases during the major part of lactation (Chilliard *et al*., 2003). Dunshea *et al.* (1989) supported this concept by saying that, as lactation advances, both plasma poly-unsaturated fatty acids (PUFA) concentrations and PUFA entry rates decrease. In early lactation, milk production is high and food intake is not sufficient to maintain energy balance; adipose tissues are mobilised (lipomobilisation) to provide energy for milk secretion. Fatty acids from body fat are then used extensively for milk triglyceride synthesis. If food intake is low and absorption of glucose and short-chain FA

from the intestine is drastically reduced, an animal can, for a limited period, primarily use body fat to sustain milk fat synthesis (Sherwood *et al*., 2005).

Mobilisation of adipose tissue (lipomobilisation) in the form of PUFA and elevated plasma PUFA concentration in goats under restriction or during prolonged malnutrition was reported by Dunshea *et al.* (1989). In a recent study, Bouattour *et al*. (2008) used goats from typically dry areas and fed them a relatively high-forage diet, adding a reasonable dose of soybean oil; milk fat was increased without negative effects on intake, milk yield and protein content. This is conversant with Morand-fehr *et al.* (1980) who indicated that the inclusion of extruded soybeans to 20% of DM prevented low milk fat for goat fed high concentrate diets, with no decrease in milk protein content. In another study on mammary lipid metabolism conducted by Chilliard *et al*. (2003) it was said, and later proven, by Lefrileux *et al.* (2008) that a fat supplemented diet to goats sharply increased the percentage of milk fat, had a variable effect on protein content but did not increase milk yield. The increase in milk fat content was attributed to the net increase in fatty acids brought to the mammary gland due to the lipid supplement in the diet. However, the same study demonstrated that the higher the intake of long chain fatty acids (C18) the lower its apparent transfer rate into milk; the explanation was the higher utilization of FA by non-mammary tissues, together with a high level of incorporation into phospholipids and cholesterol ester. This suggested that part of the FA secreted into milk comes from endogenous synthesis and release by peripheral adipose tissues (Chilliard *et al.*, 2003). Changes in adipose tissue metabolism was earlier reported by Vernon *et al.* (1981) who worked on sheep and concluded that, although there were no differences between species in the time of onset of lipid mobilisation and perhaps in the regulatory mechanisms, a pattern of lipid accumulation and mobilization during pregnancy and lactation was ubiquitous among mammals.

Milk fat is an important component of the nutritional quality of goat dairy products. Goat milk fat content and composition can be extensively modified by genetic, physiological or nutritional factors. However, fat supplementation of the diet is an efficient means to modify milk FA composition in lactating ruminants (Chilliard *et al.*, 2003). In goat milk fat percentage and FFA content are highly correlated (Agnihotri *et al*., 1993).

2.2.2.4 Milk urea nitrogen (MUN) content of goat milk

Much of the CP a ruminant consumes is degraded by rumen microbes into ammonia and used for the synthesis of microbial proteins. Ammonia is also produced from normal daily metabolism of absorbed amino acids and body proteins. Excess rumen ammonia is absorbed by the rumen wall and ammonia from tissue metabolism transported in blood to the liver and kidneys where it is converted into urea. Some of the urea circulating in blood is recycled in the saliva back to the rumen. Excess ammonia circulating in blood is very toxic, whereas urea is much less so. The conversion of blood ammonia into urea occurs in mammals as part of their normal body metabolic mechanism to prevent ammonia toxicity (Bonanno *et al*., 2008). These views were already reported by Oltner *et al.* (1983). Work conducted by Kohn *et al.* (2005) who used BUN to predict nitrogen excretion and efficiency of nitrogen utilization in goats, resulted in the finding, later supported by Arunvipas *et al.* (2007) that blood and plasma urea concentrations are proportional to MUN, they may therefore be useful as predictor in much the same way.

In conclusion, high blood nitrogen concentration is typical during lactation and because of the high positive correlation between plasma and milk urea (Khaled *et al.*, 1999), MUN can be used as an indirect indicator of protein in the diet especially for animals at pasture in which evaluating protein in the diet is particularly difficult (Pulina, 2002; Cannas *et al*.,1997;Van der Merwe *et al*., 2001; Caldeira *et al.,* 2007; Broderick *et al*., 2007; Giaccone *et al.,* 2007; Sahoo *et al*., 2008)

2.2.2.5 Somatic cell counts (SCC) of goat milk

Milk always contains leukocytes and dislodged mammary epithelial cells; the normal somatic cells that are sloughed off by the normal "somatic cells" secretion in goats consist of cytoplasmic particles which break off and are shed with milk (Das *et al*., 2000). Only 10% of the somatic cells are mammary gland cells (eosinophils, epithelial cells) normally secreted together with milk as a result of cellular turnover in the mammary gland; the remaining 90% of the somatic cells are blood cells (macrophages,

leucocytes, lymphocytes) which contribute to the immune defence of the mammary gland; their number increases considerably in the case of inflammatory or pathological processes as in mastitis (Bencini *et al*., 1997). In healthy cows there are approximately 30,000 to 300,000 cells per ml of milk. Normally half of the somatic cells are neutrophile granulocytes; but during inflammation of the udder the density of the somatic cells in milk increases 10 to 100 times.

Milk somatic cell count (SCC) has been used as a tool for assessing both animal health status and milk quality (Casu *et al.,* 2010). Many authors (Zeng *et al*.,1995; Zeng *et al*., 1996; Voutsinas *et al.* 1990) have indicated that SCC and daily milk yield vary throughout lactation depending on numerous factors such as morning versus evening milkings, stage of lactation, parity and breed. The SCC of goat milk is generally greater compared with the dairy cows (Chang *et al.,* 2006). Since the concept of "Grade Pasteurized Milk Ordinance (PMO)" was popularized in the United States (US) in 1989, the US PMO regulation regarding SCC in goat milk allows 1 x 10^6 ml^{-1} while the legal Milk SCC (MSCC) limit established by the US Food and Drug Administration (FDA) is of 10^6 for sheep and goat (Paape *et al.*, 2007). In South Africa the legal limit of SCC is set at 750 x 10^3 cells per ml (Petzer *et al*., 2008). In dairy cows the concentration of more than 750,000 ml^{-1} SCC in milk is considered indicative of mastitis in the mammary glands (Zeng *et al.,* 1995).This figure may not necessarily be applicable in dairy goats, where milk of individual infected and non-infected does often contained more than 1 x 10^6 SCC ml. Zeng *et al.* (1995) reported that 56% of milking does produced milk with 1 x 10^6. SCC ml^{-1} ; they concluded that milk from healthy does, with no signs of mastitis could contain as many as 5 x 10^6 SCC ml^{-1}.

They explained that dairy goats have a different secretory system than cows. The apocrine system of goats produce cytoplasmic particles and their milk may contain a large number of epithelial cells resulting in the exceeded limit of SCC especially in their late lactation stage. The same authors (Zeng *et al.,* 1995) reported an average of 1.3 x 10^6 SCC in bulk tank goat milk collected in November and December and that significant variations in SCC among goat herds existed ranging from 4.38 x 10^5 to 1.68 x 10^6; after examining a complete lactation of Alpine goats (March to October) they concluded that parity did not affect SCC or chemical composition of milk; and also that SCC of more

than 1 million ml^{-1} did not indicate any mastitic conditions in alpine goats. In a study conducted by Das *et al*. (1999) on variation in blood leucocytes, SCC in milk yield and composition of crossbred goats revealed that mean SCC was higher in the first biweekly period of lactation and declined steadily with advanced lactation; but in individual goats, considerable variation (8.09-44.10 x 10^5 cells/ml) existed. Furthermore, variation in SCC between the goats and between different experimental periods was highly significant ($P < 0.01$) just as it was ($P < 0.05$) between the two different breeds of goats used in the experiment.

Paape *et al.* (2006) said that there was no Milk SCC legal limit for sheep and Goat in the European Community. Mena *et al*. (1999) expressed the hope that the European Union will establish the SCC limit at 1.5 x 10^6 cells/ml. Corrales *et al.* (2004) indicated that the limit of 1.5 x 10^6 cells/ml should be acceptable for goats' milk in the European Union. No official maximum threshold is reported for goat milk SCC in Mexico, which is the main goat milk producer on the American continent (Fernandez *et al*., 2008).

In summary SCC is certainly a valuable udder health status index, but up to which threshold exactly it can be used in the dairy goat is still to be established.

2.2.3. Selected blood metabolites associated with milk production.

Blood chemistry has long been used in human medicine as a diagnostic tool. With the development of new automated analytical equipment in the sixties blood chemistry became a routine technique for the assessment of metabolic status in individuals and groups of animals. Payne (1978) grouped different blood constituents into a single package called the "Compton metabolic profile test". Rowlands (1980) introduced the concept of "blood profile" defined as a set or combination of blood constituents analyzed together depending on factors such as relevance to the problem under investigation, cost and ease of analysis and stability of samples in relation to time in transit between farm and laboratory. The blood constituents usually analyzed were PCV (packed cell volume), haemoglobin, glucose, urea nitrogen, albumin, total protein, calcium, magnesium, sodium, copper and iron. Later, free fatty acid and cholesterol were added to the blood profile because of their relationship to energy status (Ingraham *et al.*, 1988). Pambu (1997) used blood glucose, blood urea nitrogen, blood cholesterol and total protein

concentrations to evaluate the nutritional plane of indigenous goats raised on free ranging system in South Africa.

In this study, glucose, BUN, cholesterol and FFA concentrations have been selected firstly, because of their pertinence to the energy metabolism of the ruminant and secondly, because of the association of urea to the protein and nitrogenous metabolism. In the milk industry indeed, a premium is paid for the protein, lactose and fat percentage in milk.

2.2.3.1 Blood glucose concentration in goats

Glucose is synthesized from four glucose precursors: propionate, amino acids, glycerol and lactate. An abundant scientific literature supports propionate and amino acids as the most important contributors to glucose synthesis. Lindsay (1971) and Bergman (1983) said that between 45 and 75% of the total glucose produced derived from propionate and amino acids. Donna *et al.* (1990) and Weekes (1991) suggested that between 20 and 56% of the total glucose synthesized derived from propionate. Eisemann *et al.* (1994) claimed that, of the total body glucose production, 85% arose from the liver; 90% of all the propionate produced is removed by the liver for glucose synthesis. Findings of Bickerstaffe *et al.* (1974) established earlier that the hepatic glucose production derived mainly from propionate and glucogenic amino acids, namely alanine and glutamine: the two major amino acids used for glucose synthesis. Of the total glucose production, between 15 and 32% originated from amino acids (exogenous) source or, (in case of food deprivation) from muscle protein catabolism whereby the carbon skeletons of the amino acids released were used for gluconeogenesis, while nitrogen was converted into urea and excreted in the urine (Bergman, 1983).

Glucose from the gastro-intestinal absorption represents between 0 and 6% of the total glucose turnover (Sutton, 1985). The major part of dietary glucose is used as a source of energy by the gut and little, if any of it, reaches the liver (Bergman, 1983; Weekes, 1991; Balcells *et al.*, 1995). Hormones related to glucose metabolism are insulin, glucagon and growth hormone. The capacity of insulin to suppress endogenous glucose output is well documented (Weekes, 1991; Chang *et al.*, 1996). Eisemann *et al.* (1994) showed that the total splanchnic release of glucose declined linearly as amount of

infused insulin was increased. Glucagon is associated with an increase in blood glucose concentration. It (glucagon) causes glycogenolysis followed by gluconeogenesis. If glucagon fails to raise blood glucose concentration sufficiently, epinephrine is secreted from the adrenal medulla. The combined effect of these hormones will increase glycogenolysis and lipolysis. Glycerol will be mobilised and free fatty acids will become available as an alternative fuel for oxidation. The overall result will be an increased blood glucose concentration. The other important hormones in this respect are cortisol, growth hormone and prolactin. While cortisol and growth hormone increase protein catabolism (and therefore glucose concentration), prolactin mobilizes adipose lipid stores. This in turn results in an increased concentration of glucose precursors (Baumann *et al.,* 1980).

Under normal circumstances, between 20 and 30% of the total glucose production is oxidized by the ruminant brain. Up to 10% is converted into glycogen by the liver, while up to 30% is deposited as fat. The remainder is used as an energy source by muscle. During pregnancy fetal oxidative metabolism removes up to 40% of total maternal glucose production, while between 85 and 90% is taken up by the mammary gland during lactation (Baumann *et al*., 1980; Bergman, 1983; Weekes, 1991). The apparent contribution to mammary gland metabolism is:

- Glucose>Acetate>β-hydroxybutyrate>FFA for the lactation phase; and
- Acetate>β-hydroxybutyrate>Triacylglycerols for the involution stage, with no positive uptake of glucose and FFA (Chang *et al*., 1996).

The primary requirement of glucose by the mammary gland during lactation is to serve as a precursor to lactose synthesis (Rook *et al*., 1966). Lindsay (1971) showed that food intake is a major determinant of increased blood glucose production during lactation; this was also the view of Sahlu *et al*. (1992) who observed high glucose concentrations in goat fed high energy diets; apparently, an increased glucose production resulted from greater availability of glucogenic AA present in the diet. Many authors (Bergman, 1983; Weekes, 1991; Hossaini-hilali *et al*., 1993; Landau *et al*., 1993 and Rusche *et al.,* 1993) showed that increased food intake resulted in high blood glucose

concentration in lactating animals. In contrast, a low blood glucose concentration during lactation was reported (Rowlands, 1980; Manston *et al*., 1980); this decrease, according to Ingraham *et al.* (1988), commonly observed in high yielding cows, can be attributed to the fact that during early lactation the ruminants are unable to eat sufficient food to meet their high metabolic demand; this put the high producing animal in a critical nutrient balance and affects blood metabolites concentrations for 60 days more after calving.

Glucose and cholesterol are among the blood constituents that are most affected. Amaral Phillips *et al.* (1993) investigated the short-term effects of decreased availability of glucose in dairy cows. It was concluded that fat and protein are mobilized from adipose and muscle tissue to provide gluconeogenic precursors after reserves of liver glycogen are depleted. Hossaini-Hilali *et al.* (1993) observed that plasma glucose concentrations decreased more rapidly in lactating than in non-lactating goats because more glucose was used for lactose synthesis in the lactating goats resulting in a depletion of the glucose pool.

These results were later supported by Hussain *et al.* (1996) who showed that plasma glucose concentrations were lower in the underfed goats as compared to the well fed group. From the above, it can be concluded that a low blood glucose concentration is typical of lactation (Rowlands, 1980; Ingraham *et al*., 1988) but in case of an imbalance between supply and demand during lactation, body reserves are mobilized, followed by increased blood glucose concentration. In this case animals will display a higher than expected blood glucose concentration accompanied by high level of urea nitrogen concentration.

Glucose is critical during lactation because its uptake by the mammary gland is essential for the synthesis of milk lactose, the major osmotic regulator of milk volume. The pancreatic hormones insulin and glucagon are key controls of glucose homeostasis: acute regulation of plasma glucose concentration by reciprocal actions of insulin and glucagon ensure the proper balance in glucose supply and utilization by body tissues and organs during lactation (Bauman *et al*., 1980).

Blood glucose concentrations have been, on one hand, used by some as an index of energy status in ruminants (Payne, 1970; Rowlands, 1980; Ingraham *et al*., 1988; Pambu *et al*., 2000). On the other hand, Erfle *et al.* (1974) and Russel (1983) have

warned that blood glucose concentrations, because of their sensitivity to homeostatic control and also to adrenal cortical influence, are unsatisfactory as an index of energy status. Lately, Caldeira *et al*. (2007) wrote that the ruminant energy status predictors included plasma and serum glucose, insulin, glucagon, non-esterified fatty acids (NEFA) ß-hydroxybutyrate, triacylglycerols and total lipids.

From all these, glucose, NEFA and insulin provided more substantial information for the diagnosis of the animal's energy status. Blood glucose and blood urea nitrogen concentrations can be used to monitor nutrient status in goats (Turner *et al.,* 2005). In this study, they have been selected to evaluate the adequacy of energy intake in lactating goats raised in small scale farming systems.

2.2.3.2 Blood urea nitrogen (BUN) concentration in goats

Most of the Non-Protein Nitrogen (NPN) and protein material ingested by the ruminant are degraded by the rumen microbiota into ammonia (NH_3) which is readily absorbed through the lining of the rumen reticulum and omasum (Bonanno *et al*., 2008). Rumen microbes use ammonia along with some amino acids and polypeptides to synthesize their own microbial proteins. Once these bacteria are swept into the abomasum, their cell proteins are digested and eventually absorbed through the small intestine.

The synthesis of microbial proteins also ensures that the host animal is supplied with essential as well as non-essential AA (Sherwood *et al*., 2005). Between 30 and 40% of dietary protein entering the rumen is not degraded and is classified as rumen–undegradable protein (RUP) which can be hydrolysed only by the gastrointestinal proteolytic enzymes. Ammonia generated in the reticulo-rumen is either converted into microbial proteins or converted into urea in the liver. Some of this urea is returned to the forestomach directly through the wall of the reticulo-rumen or through the salivary glands. High urease (urea-digesting) activity is found along the ruminal wall and is responsible for the rapid degradation of urea to ammonia for metabolism into microbial proteins (Bonanno *et al*., 2008).

When environmental conditions become particularly harsh and the only herbage available is deficient in protein, the concentration of ammonia in the rumen is low, as are

the number of rumen microbes; the breakdown of cellulose will slow down; the total amount of nitrogen returned to the rumen as urea exceeds that absorbed from the rumen as ammonia, nitrogen recovered through this process is converted to microbial proteins. Ultimately the total amount of protein arriving in the intestine can be greater than that of the original food. A ruminant can conserve an important nitrogen source by returning to the rumen urea that would otherwise have been excreted as urine (Goshtasbpour-Parsi *et al*., 1974). Alternatively in conditions where protein degradation is greater than its synthesis, such as in animals fed rich concentrates, ammonia can potentially accumulate in the rumen fluid, be converted into urea in the liver before excretion in urine and be wasted (Sherwood *et al*., 2005); in the Angora and the Boer goat for example, between 38 and 58% of urea influx can be lost in this way (Cronje *et al*., 1992). During fasting or inadequate nutrient intake, the animal mobilizes body reserves (muscle protein catabolism) and amino acids (AA) become available (Folman *et al.*, 1981). In goats, this all sequence of events has been represented by Harmeyer *et al*. (1980) on Figure 1.1 (below).

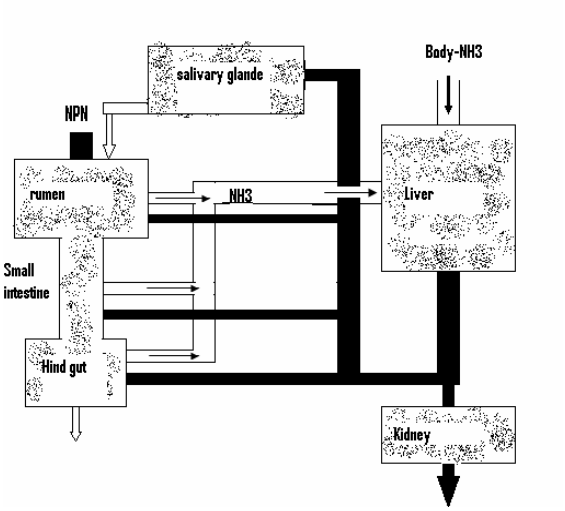


Figure 1.1: Diagrammatic illustration of urea metabolism in the goat (Harmeyer and Martens, 1980)

Deamination of the AA (from Body reserves) for gluconeogenesis in the liver will result in the production of urea (Ganong, 1995). Gluconeogenesis and ureogenesis are therefore linked processes (Bergman, 1983; Belyea *et al.*, 1990). Of the urea synthesized in the liver, between 30% and 58% can result from deamination of amino acids (Nolan *et*

al., 1972; Lindsay, 1971). In goats as in other ruminants, renal mechanisms may also contribute to urea conservation during protein deprivation (Eriksson *et al.,* 1981).

The hormonal factors affecting blood urea concentration are linked to those affecting blood glucose concentrations. When blood glucose concentration falls, the insulin: glucagon ratio decreases in favor of glucagon which will stimulate breakdown of amino acids from muscles (Bergman, 1983). The AA carbon skeleton will be used to synthesize glucose, while the amino radicals will be converted into urea, resulting in an increased blood urea concentration. Glucagon, cortisol and growth hormone influence blood urea concentration indirectly. Glucagon in particular can increase the uptake of alanine, glutamine and other glucogenic amino acids by the liver (Bergman, 1983). If the chronic food shortage continues, long-term hormonal adjustments will take place resulting in increased secretion of epinephrine (Bergman, 1983).

The association between the reduced insulin secretion and the glucagon plus epinephrine secretion will further increase glycogenolysis and rapidly cause lipolysis in adipose tissue followed by mobilization of glycerol and free fatty acids. The increased supply of glycerol will in turn increase gluconeogenesis and the free fatty acids released will provide alternative fuel for oxidation by the body (Bergman, 1983; Ganong, 2005). Schrick *et al.* (1990) fed Angus and polled Hereford cows' diets of high or low energy content and studied the effect of dietary energy restriction on metabolic and endocrine responses during estrus cycle of suckled beef cows. Cows fed the low energy content diet had higher blood urea nitrogen concentrations. This was explained by the fact that those animals were in a state of energy deficiency; muscle protein was catabolised to produce AA which in turn contributed to a gluconeogenesis and the subsequent ureogenesis. It indeed appears that high BUN concentration is typical during lactation. This is not only because of the increased rate of urea recycling to the reticulo-rumen but also because of the negative energy balance which occurs during early lactation and which results in AA deamination and consequently in gluconeogenesis and the subsequent ureogenesis (Brun-Bellut,1996).

Similar conditions prevailed when Khaled *et al.* (1999) investigated the changes in the concentration of blood and milk constituents of dairy goats under the effects of stable diets. They found a high amount of serum NEFA, blood total ketones and BUN

concentration in the first lactation months and concluded that this was subsequent to the energy deficit associated to the considerable metabolic changes occurring in the high yielding dairy goats. Hoaglund *et al.* (1992) studied the effects of supplemental protein source and metabolizable energy intake on nutritional status in pregnant ewes. It appeared that BUN (and albumin) concentrations were higher in ewes fed blood meal plus soybean meal than in ewes fed soybean meal or urea only. These results are in agreement with those of Palmquist *et al.* (1978); Park (1985); Dhiman *et al*. (1991); Nikokirys *et al.* (1991); Rusche *et al.* (1993); Sahlu *et al.* (1993); and Diab *et al*. (1996) who indicated :

1) That an increased BUN concentration can result from increased dietary crude protein intake, and that a low crude protein intake is associated with low BUN
2) That a low dietary energy supply is also associated with higher BUN concentration as a result of the mobilization of body reserves for gluconeogenesis and the subsequent ureogenesis;
3) That BUN can possibly be used as an index of fertility in cows fed excess ruminally degradable protein.

Caldeira *et al*. (2007) wrote that the protein status predictors included serum albumin, globulins, total protein, urea and creatinine. Of these, serum albumin and urea concentrations are good metabolic indicators of the animal's protein status. This is also the opinion of Kohn *et al.* (2005) who claimed that BUN concentration may be useful as a protein status index. In the present study, BUN concentration has been selected to evaluate the adequacy of protein intake in lactating goats raised on small scale farming system.

2.2.3.3 Blood Cholesterol concentration in goats.

Cholesterol biosynthesis can take place in several organs, the liver and the intestines being the most important sites of production. A distinction must be made between dietary (exogenous) cholesterol and endogenous cholesterol (from extrahepatic tissue synthesis) (Beynen *et al.*, 2000). It has been shown that dietary saturated fat elevates plasma cholesterol concentrations in many species (Diersen-schade *et al.*, 1984) and the easiness with which dietary cholesterol enters and crosses membranes in the

animal body has been demonstrated by Raphael *et al*. (1975). Dietary cholesterol esters in the intestinal lumen are converted into cholesterol by pancreatic cholesterol ester-hydrolase. The free cholesterol produced, together with free cholesterol in the diet and in the bile, is taken up by absorptive cells in the mucosa of the small intestine. Here cholesterol is re-esterified into cholesterol-esters, and these are transported via the lymph in chylomicrons (Kaneko, 1989). The nascent chylomicrons enter the blood via the lymphatic ducts before disposing of their triacylglycerols into tissues such as adipose tissues (Ganong, 2005).

The chylomicron remnant brings cholesterol to the liver. From the liver, cholesterol is dispatched to different extrahepatic organs (intestines, adrenals, kidneys, heart, mammary glands, lung, ovaries, skin, muscle and brain). In the liver, cholesterol is also incorporated (as such, or after transformation) into bile. Bile is secreted into the small intestine where cholesterol will be either reabsorbed in the intestinal mucosa, or excreted in the faeces (Dietschy *et al.,* 1995). An additional source of cholesterol is acetate, one of the three VFA's resulting from the dietary carbohydrates fermentation in the rumen. In this case, part of acetate circulating in the peripheral blood is removed from the portal blood in the liver where it is used for *de novo* synthesis of the long-chain fatty acids and cholesterol. In the peripheral organs (muscle, portal drain viscera, adipose tissue as well as in the liver) acetate will be oxidized and *de novo* synthesized cholesterol will result from acetyl CoA (Miller *et al*., 1991). In plasma, cholesterol is carried in lipoprotein complexes known as VLDL (very low density lipoproteins) LDL (low density lipoproteins) and HDL (high density lipoproteins) (Beynen *et al.*, 1989). The cholesterol portion carried in chylomicrons and delivered to the liver is incorporated into VLDL-cholesterol which in turn will bring triacylglycerols to peripheral tissues for oxidation; in this process VLDL-cholesterol will be transformed into LDL-cholesterol which will be reabsorbed mainly (80%) by the hepatic LDL-receptors and at the lower rate by the adrenals. It is believed that cholesterol from peripheral synthesis is the most important contributor to the total cholesterol turnover. This sequence of events is shown in Figure 1.2 represented on next page.

As said earlier, cholesterol is used in the liver (as such, and as bile acid precursor); at this level, any cholesterol that cannot be reabsorbed will exit the body via faeces (Beynen,

2000). As a steroid hormone precursor, cholesterol used by various organs (ovaries, adrenals) is excreted from the body in the urine. The role of cholesterol as a structural component of most cell membranes and as a vitamin D precursor is also well documented; as such, it is essential for animals from which it is lost through sloughing of the intestinal mucosa and the skin (Zubay, 1986).

The cholesterol content of milk in the goat is usually in the range of 10 to 20mg/100ml (Jenness, 1980). The cholesterol content of colostrum is much higher (40mg/100ml). Milk cholesterol may derive from blood or from *de novo* synthesis from acetate within the mammary gland (Long *et al.,* 1980). Although milk cholesterol is synthesized in the mammary gland, it derives principally from serum cholesterol which equilibrates with membrane cholesterol of the lactating cell prior its secretion in milk (Long *et al*, 1980).

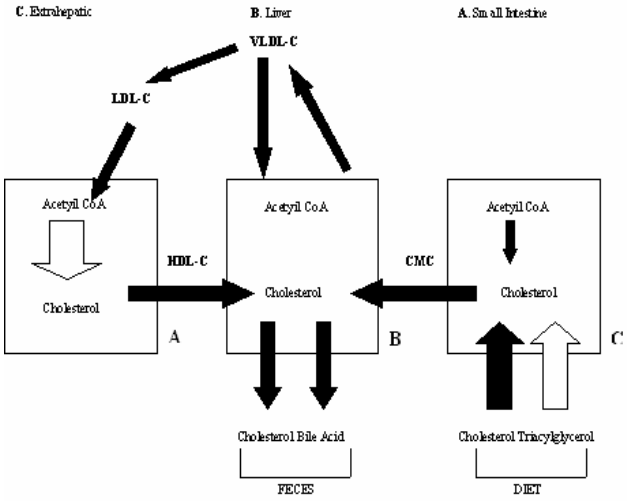


Figure 1.2: Cholesterol metabolism in cynomolgus monkeys (Source: Turley, Spady & Dietschy, 1995)

The demand for cholesterol by the mammary gland will differ according to the stage of lactation, with particularly acute changes occurring at the onset and cessation of lactation. The uptake of cholesterol from plasma lipoproteins is increased during lactation (Botham *et al.*, 1993). In goats, chylomicrons make an important contribution to mammary lipid uptake (Bickerstaffe *et al.,* 1974). In most cases, the liver functions to present a constant concentration of cholesterol to the extrahepatic tissues. Consequently, under normal situations, the hepatic cholesterol contribution is a reflection of the balance

between the demand by various tissues and the supply of exogenous and endogenous cholesterol. If the dietary cholesterol content is increased, hepatic cholesterol synthesis will decrease and faecal loss will increase so that equilibrium is maintained. On the other hand, if a low-cholesterol cellulose diet is fed, the plasma cholesterol concentration will be low (McCall *et al.,* 1992), and the hepatic cholesterol contribution will be increased (Dietschy *et al.,* 1995). During pregnancy or lactation, however, the higher cholesterol demand exceeds the hepatic compensatory capacity (Ruegg *et al.*, 1992; Nielsen *et al*., 1994). If the extra cholesterol required is not supplied through the diet, a negative energy balance will result with a drop (below 50mg/dl) in the total cholesterol concentration (Dietschy *et al.,* 1995).

The reverse is also true: lipid-rich diets result in an increased amount of cholesterol reaching the liver which will in turn, raise the plasma cholesterol concentration (Yang *et al.*, 1978; Grummer and Carroll, 1988; Ruegg *et al.,* 1992; Kadzere *et al*., 1993; Lin *et al*., 1994; Dietschy *et al*., 1995). There are also cases (starvation, food scarcity) where the animal has to mobilize body reserves; blood cholesterol concentration will, under such circumstances, be elevated (Grimoldi *et al.*, 1988).

A number of authors (Yang *et al*., 1978; Grummer *et al*., 1988; Hiromasa *et al*., 1990; Caldeira et al., 1991; Ruegg *et al*., 1992; Lin *et al*., 1994; Miettinen *et al.,* 1994; Weiss *et al*., 1994) have shown that a higher plasma cholesterol concentration is caused by feeding lipid rich diets, or diets rich in cholesterol precursors. Others (Ingraham *et al*., 1988; Ruegg *et al.,* 1992) have indicated that high cholesterol concentrations in the absence of excess dietary fat intake are a reflection of the capacity of the animal to mobilize body energy reserves. Nachtomi *et al.* (1991) found that blood cholesterol concentrations increased during the first five weeks of lactation in high producing dairy cows. A possible explanation is that the increased demand for energy required for production of milk and milk fat resulted in fat mobilization from fat reserves; this was in turn followed by an increase in blood cholesterol concentration as has been reported by Grimoldi *et al.* (1988). Wiley *et al.* (1991) found that cholesterol concentrations were lower in first calf beef heifers fed undegradable protein than in heifers fed rumen degradable protein. Although the relationship between protein and cholesterol is not well

defined, Park (1985) suggested that the amount of protein ingested affected the rate of cholesterolgenesis. The results of Wiley *et al*. (1991) can possibly be explained in the light of the assumption that the solubility of protein may have an effect on the rate of cholesterolgenesis. Arave *et al*. (1974) studied the genetic and environmental effects on serum cholesterol concentrations of dairy cattle of various ages. It was found that serum cholesterol concentrations were relatively low at the onset of lactation, increased at mid-lactation and levelled off or decreased in late lactation. This was in agreement with Rowlands *et al*. (1980) who studied metabolic changes in dairy cows during pregnancy and late lactation and found a significant increase in blood cholesterol concentrations between week one and six post- partum.

From the above, it can be concluded that blood cholesterol concentration is affected by lactation especially in early lactation, and also in the case of body reserves mobilization; blood cholesterol concentration is however, complicated by the relationship between cholesterol concentrations and hormones involved in reproduction. In the present study blood cholesterol concentration has been used to evaluate the adequacy of energy intake in lactating indigenous goats raised in small scale farming system.

2.2.3.4 Blood free fatty acids (FFA) concentration in goats

The major fats in grains are triglycerides that contain a high pproportion of linoleic acid (C:18:3) whereas in forages the lipids are in the form of galactoglycerides whose main fatty acid is linolenic acid (C: 18: 2). Most forages and seeds or grains do not contain high proportions of lipids; only about 40 to 60g per kg DM. These lipids contain a high proportion of residues of the C:18 poly-unsaturated fatty acids, namely linoleic and linolenic acids. Grasses contain more α-linolenic acid (C18:3) whereas grains contain primarily linoleic (C18:2) and oleic acids (C18:1). In ruminants, more than 90% of triacylglycerides and other plant lipids in feed are hydrolyzed in the rumen and more than 90% of these unsaturated fatty acids are completely hydrogenated in the forestomach, forming stearic acid (C18:0) (Meissner, 1994).

In most animals, between 40 and 50% of fatty acids used by the mammary gland for milk fat synthesis are produced in the mammary epithelial cells by *de novo* synthesis from smaller components such as acetate in ruminant and glucose in single-stomached

animals; the other half of fatty acids are taken up from the blood. Esterification of fatty acids takes place in the endoplasmic reticulum of the cells; the reaction utilizes α-glycerophosphate which is formed in the cells from glucose or from glycerol (Zubay, 1986). Mono and Di-glycerides taken up from blood are also esterified; the short–chain fatty acids (C4) are esterified primarily to carbon 1 and 3 in the glycerol molecule, while the long chain fatty acids bind to the middle carbon atom in position (C2). Nearly all the fatty acid molecules in milk are esterified. Newly synthesized milk therefore has very low concentrations of free, unesterified fatty acids (Sherwood *et al*., 2005). Milk fat per cent and FFA contents are highly correlated in goat milk (Agnihotri *et al.,* 1993).

In early lactation, milk production is high and food intake is not sufficient to maintain energy balance. Fatty acids from body fat are then used extensively for milk triglycerides synthesis (Chilliard *et al.*, 2000; Doepel *et al.*, 2002). If food intake is low and absorption of glucose and short chain fatty acids from the intestines is drastically reduced, an animal will, for a limited time, primarily use body fat to sustain milk synthesis. During *de novo* synthesis the udder epithelial cells forms fatty acids from precursors like acetate and β-hydroxybutyrate formed in the rumen wall. Precursors for the lipids synthesized and secreted by the mammary epithelial cells are therefore from the diet or from adipose tissues (Sherwood *et al.*, 2005).

Miettinen *et al*.(1989) worked on the concentrations of blood metabolites and their relation with fatty acids composition of dairy cow milk; it was found that milk fatty acids *de novo* synthesized (C6-C16) were positively correlated (while the long chain fatty acids (C16) entirely derived from blood were negatively correlated) to the estimated metabolizable energy balance. It was concluded that blood aceto-acetate and plasma NEFA and glucose concentrations are the best indicators of the cow's energy status. This is in agreement with Dunshea *et al.* (1989) who studied the relations between plasma NEFA metabolism and body tissue mobilization during chronic undernutrition in goats; not only did they write that plasma NEFA concentrations could be used as an index of chronic energy status, but they also observed an elevated NEFA concentration during acute energy restriction; the explanation was that adipose tissue was mobilized in the form of NEFA.

An elevated milk fat content after parturition with a decrease during the major part of lactation in goats was also observed by Chilliard *et al.* (2003). Bernard *et al.* (2005) studied the mammary lipid metabolism and milk fatty acid secretion in Alpine goats and found that a fat supplemented diet to goats sharply increased the percentage of milk fat but did not increase milk yield; and also that plasma NEFA in lactating goats was not influenced by diet differing in type and level of fat, contrasting with the increase of plasma NEFA observed by Rukkwamsuk *et al.* (1998) in cows receiving dietary fat. It was suggested that regulation of mammary cells do differ between caprine and bovine species, particularly in the elongation process of fatty acids which are *de novo* synthesized by the "fatty acid synthetase" complex; for this reason the homeorhetic control on the lactating goat may have set mechanisms whereby milk fat precursors were derived primarily from the body reserves and indirectly only from dietary fat. This non-responsive attitude of lactating goat fed rich-fat diet was also observed by Luna *et al.* (2008) when they studied the effect of diet enriched in whole linseed and sunflower oil on goat milk fatty acids composition. Certain diets cause a marked reduction in milk fat production in ruminants (Bauman *et al*., 2003)

The nutritional advantage of goat milk fat compared to cow milk has been attributed to the high content of caproic acid (C6) and capric acid (C10), to its lack of agglutinin, and to its high percentage of short and medium chain fatty acids esterified on carbon 3 of the glycerol skeleton and also to the small size of its fat globule (Luna *et al.*, 2008). For this reason, a lot of interest has been shown in goat milk fatty acids composition and many attempts to modify them through nutrition have been made in order to derive a quantitative advantage on goat milk products. However, it seems that such changes, may adversely affect the flavour and nutritional properties of dairy goat products (Luna *et al*., 2008).

2.3. Phenotype score (PTS)

The concept of phenotype score (PTS) is new. It has been developed as a tool to assist the goat farmers who want to make predictions on their lactating does' (quantitative and qualitative) milking potentialities. PTS has been also developed as an instrument to

help the farmers fine-tune management decisions in order to improve their goat milking productivity. PTS consists in a critical analysis of data gathered from the BCS, breed, udder characteristics and age, their interactions and their implication at the metabolic (therefore their productivity) level. In practice PTS does not yet exist; whence the limited literature dealing with this subject; however, BCS is quite well documented while reports on goats'phenotype characteristics (breed, udder characteristics) and age are scanty and remain substantially limited.

2.3.1 Body condition scoring (BCS) in goats

It is generally acknowledged that live weight and body condition are connected to productivity in the ruminant (Majele-Sibanda *et al*., 2000). Body condition scoring is a fairly simple and efficient tool to assess the health and nutritional status of animals (Nix, 2004). It is used to evaluate an animal's body fat in relation to the amount of muscle it possesses (Coffey *et al*., 2009). The term "body condition" refers to the fleshiness of an animal (Luginbuhl *et al*., 2009). It is an estimate of the muscle and fat development of an animal (Cobb, 2008). Animal body condition is considered to be an indicator of fat reserves; and fat reserves in animals reflect the production performance of the herd (Santucci *et al*., 1991). It involves the visual appraisal and (or) palpating certain areas of the animal's body and assigning to the animal a numerical score on a five-point scale: 1 (for an extremely thin animal) to 5 (for a very over-conditioned – obese – animal) (Garcia *et al*., 2008). In the specific case of goats, BCS has been recognized as an important practical tool in assessing the goat's body general appearance, because BCS is the best simple indicator of the fat reserves which can be used by the animals in periods of high energy demand, stress or suboptimal nutritional conditions (Sahlu *et al*., 2007). BCS may be helpful in three ways: i) assessment of the relative changes in body composition may help in evaluation of nutritional status, leading to the determination of the adequate period of reproduction and to an optimal management of feed supplementation. ii) BCS may be a tool to assess acceptability of carcasses for meat markets (Aumont *et al*., 1994). iii) Under farm conditions BCS is an important tool to assess the adequacy of feeding programmes (Caldeira *et al.,* 2007). When overall body condition starts to decrease in the goats, it is a sign that managerial intervention such as supplemental feeding, deworming

or pasture rotation is needed. Conversely, when overall body condition starts to increase in the herd, it is a sign that the producer should reduce supplemental feeding. Goats need to be maintained at a moderate amount of body condition (Caldeira *et al*., 1991). BCS is therefore a useful tool to manage food in the herd (Pennington, 2009).

However, some authors regard BCS as a subjective estimate (Halachmi *et al*., 2008; Hady *et al.*, 1994; Garcia *et al*., 2008). Factors such as the evaluator, gut fill, amount of hair and amount of muscle can mask the true body condition of the animal (Coffey *et al*., 2009). Moreover, it can be difficult to make an accurate estimate of the goat's body condition, especially in dairy goats, which deposit much of their fat intra abdominally and are naturally bony and scrawny looking (Catton *et al*., 2002); goats have indeed the ability to deposit considerable fat internally and this may lessen the accuracy with which body composition can be predicted from BCS (Ngwa *et al.,* 2007). Other authors (Van Niekerk *et al*., 1988; Eknaes *et al.,* 2006: Luginbuhl *et al*., 2009) have also supported the opinion that simply looking at a goat and assigning its BCS can easily be misleading. BCS cannot be assigned by simply looking at the animal, instead the animal must be touched and felt (Sahlu *et al*., 2007). One example that BCS is too simple an estimation is that, in the US, only 5% of the dairy herd managers do assign a BCS to their cows (Schultz *et al*., 2008).

2.3.2 Breed

The goat world population is estimated at 746 million (FAOSTAT, 2010) in which approximately 300 breeds of goat have been identified. In Africa, goats are generally divided between meat, dairy and dual purpose breeds. Most goats however, still serve multipurpose functions for their owners. Very few breed-improvement programs have been made to develop the goats for more specialized economic functions such as meat or milk production (Mba *et al*., 1975; Ahuya *et al.*, 2009). Notwithstanding the above, in South Africa, goats are grouped into four categories: i) the Angora goats, basis of the mohair industry; ii) the dairy goats namely, the Saanen, the Toggenburg and the Alpine breeds; iii) the Improved Boer goat, a cross between the African, the Dutch and the Indian breeds developed in the Eastern Cape iv) the Indigenous goats, which are widely distributed throughout the country are extremely popular in the communal rural areas

(Mammabolo *et al.*, 1998). Worldwide, Devendra (1980) has reported the following breeds as being well-known for their high milk yielding capacity: i) The Saanen (UK) : 1227 kg/milk/365 days ii) The Anglo-Nubian (UK): 989 kg/milk/ 365 days iii) The Damascus (Cyprus): 300-600 kg/milk/ 240 days iv) The Jamnapari (India): 235 kg/milk/ 261 days v) The Barbari (India): 144kg/milk/235 days. vi) and The Sudanese Nubian (Sudan): 40 kg/milk/lactation.

Among the European breeds raised in the tropics attention should be focused on the Anglo-Nubian, the Toggenburg, the British Alpines and the Saanen (Devendra, 1980). The Alpines, Saanen and Toggenburg breeds originated in the French and Swiss Alps; they are referred to as "Swiss" type breeds (Harris *et al*., 2003); nowadays, they are also found in South Africa. In this study, these breeds have been selected and raised together with the indigenous goats an in a small scale farming system at the (Agricultural Research Council) Animal production institute of Irene, nearby Pretoria.

2.3.3 Udder characteristics

This term refers to the udder circumference (perimeter) and udder depth, traits that describe the udder volume (size); it also includes the length, the cleft and the level of attachment of the udder. A phenotypic correlation has been found between these traits and milk production (Mavrogenis *et al*., 1989). Montaldo *et al.* (1993) worked on phenotypic relationships between udder and milking characteristics; they found that globular (maximum perimeter) udders had a significant positive correlation with daily milk production. Peris *et al.* (1999) studied the relation between udder and milking traits in Murciano goats in Spain; a positive correlation (0.69) was found between udder volume and milk yield. In the day to day farming practice however, farmers cull any does with hanging (maximum length) udders because the latter are exposed to injuries and infections. Casu *et al.* (2010) summarized this by saying that the appraisal of the udder is a useful tool for culling decision aimed at increasing sanitary status of the flock. Animals with deep and pendulous udders are more prone to udder inflammation or mastitis. Horak and Kasing (1970) suggested that selection for certain morphological characteristics of the udder should be made since their correlation with milk production responses were favourable. Montaldo *et al.* (1993) contended that information concerning correlations

with such characteristics in goats is scarce, but knowledge about these relations is critical to design breeding programmes aimed at improving milkability and udder health in the goats. This opinion was also supported by Dzidic *et al*., (2004) who said that knowledge of milk yield and udder conformation is necessary because a larger udder determines an increased milk production. Berry et al. (2002) said that a good doe should have large udder before and considerably smaller udder after milking; does with pendulous udders, which are prone to injury and infection should be avoided. Harris *et al*., (2003) warned against mastistis, udder oedema and congestion commonly found in high producing dairy goats. In this study udder size (volume) and udder attachment (length) have been considered in correlation with the udder milk yielding capacities.

2.3.4 Age

Age structure has a direct influence on production, reproduction and genetic progress of a breeding flock (Erasmus *et al*., 1985). In goat farming more especially Mavrogenis *et al*. (1989) wrote that udder circumference and udder depth were increasing with age, reached their maximum at 50 months (4^{th} lactation) and declined slightly thereafter. Raats *et al*. (1983) added that maximum milk production was reached at an earlier age. Ilahi *et al.* (1999) studied milking characteristics of dairy goats and saw that age of the female, lactation stage and their interaction had a highly significant effect on milk yield. They explained this by saying that adult goats had a higher production level than the primiparous probably because of the interaction between milk secretion level and the development of the mammary gland; and also because of a possible decrease in udder wall and muscle tonicity during the productive life of a dairy goat (Mavrogenis *et al*. 1989). Akinsoyinu *et al*. (1977) studied milk yield and composition in the West African dwarf goat in Nigeria and reported that mature goat milk had a higher concentration of fat and lactose. In dairy goats, age and season of kidding are important sources of variation in milk production (Mavrogenis *et al*., 1989).With the above in mind, goats aged 1, 2 and 4 years old have been selected in this study.