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Happy Days Dairies Ltd. Article Series

Article #3 - Goat Milk's Superior Nutrient Absorption Qualities
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Released April 29, 2013

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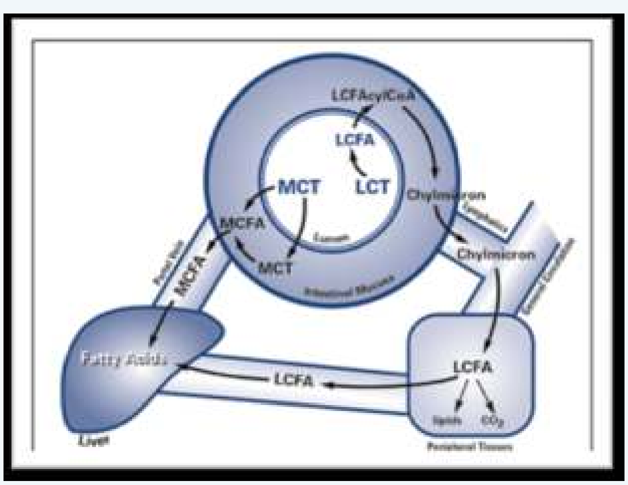
Introduction
The production of goat milk is a dynamic and expanding industry that has been proven to be essential to the wellbeing of millions of people worldwide. The overall nutrient composition contributing to the superior nutritive qualities of goat milk was described in detail in Articles 1 and 2. Here, we highlight the key macro and micronutrients that play important roles in nutrient metabolism and absorption that set goat milk apart from other dairy alternatives, particularly for the purposes of treating symptoms of nutrient malabsorption and malnutrition.

Nutritional Composition Advantageous for Nutrient Absorption
Fat

Triacylglycerols (TAGs) make up the largest portion of milk lipids (nearly 98%), and are present in the form of globules. The TAGs found in goat milk are mainly short- and medium chain length, and the average fat globule size is smaller than that of cow milk globules. These features make the fat in goat milk more advantageous for digestibility and more efficient in lipid metabolism compared with cow milk fat. (Park et al., 2007)
Medium chain triglycerides (MCTs) have been studied for their wide range of positive health benefits. Dietary fats are composed of carbon atom linkages ranging from 2 to 22 carbon atoms in length. Long chain triglycerides (LCTs), more commonly found in cow milk, ranges from 12 to 18 carbons long, while medium chain triglycerides are composed of only 6 to 12 carbon links. This shorter chain length is what gives these fats a nutritional advantage in terms of absorption over the more common long chain triglycerides, as they are able to passively diffuse from the gastrointestinal tract to the portal system without the need for modification like LCTs (Figure 1).
In addition, the fat-digesting enzyme, lipase, is able to break down the ester linkages of MCTs much faster than LCTs. Furthermore, MCTs do not require the secretion of pancreatic bile salts for digestion. MCTs are therefore commonly used to treat patients that are malnourished or suffer from



(Dean & English, 2012)

Protein
Goat milk proteins are similar to the major cow milk proteins as they both contain β-, κ-caseins, β –lactoglobulin, and α-lactalbumin, however they differ in genetic polymorphisms. Goat milk contains a greater amount of β-casein and α-S2 caseins, whereas the major casein in cow milk is α-S1. Goat milk casein micelles are therefore larger in size, less solvated, more susceptible to heat denaturation, and contain more calcium and phosphorus. These differences are responsible for the more facilitated digestibility and greater protein usage of goat milk. The average amino acid composition of goat milk (Table 1) shows higher levels of six of the ten essential amino acids (threonine, isoleucine, lysine, cysteine, tyrosine and valine) in comparison to cow milk. The higher content of cystine and lysine in particular have been shown to contribute to increased dietary mineral absorption (Kumar et al., 2012)
Table 1: Average essential amino acid composition (g/100g milk) in proteins of goat and cow milk

	Goat milk	Cow milk	Differen for go
Essential amino acids			
Tryptophan	0.044	0.046	
Threonine	**0.163**	**0.149**	**+9**
Isoleucine	**0.207**	**0.199**	**+4**
Leucine	0.314	0.322	
Lysine	**0.290**	**0.261**	**+11**
Methionine	0.080	0.083	
Cystine	**0.046**	**0.030**	**+53**
Phenylalanine	0.155	0.159	
Tyrosine	**0.179**	**0.159**	**+13**
Valine	**0.240**	**0.220**	**+9**

(Haenlein et al., 2004)

Vitamins & Minerals
The mineral content of goat milk is much higher than both human milk and cow milk (Table 2). In addition to greater levels of potassium, and chloride, goat milk is also more abundant in calcium, phosphorous and magnesium, which are essential minerals for the maintenance of bone health. Furthermore, higher amounts of vitamin A, vitamin C and vitamin D contribute to the enhanced absorption of certain essential nutrients, thereby making goat milk a great dietary component to treat nutritional deficiencies (Park et al., 2007).

Table 2: Mineral and vitamin contents (per 100 g) of goat, sheep, cow and human milk

Constituents	Goat	Sheep	Cow	Human
Mineral				
Ca (mg)	134	193	122	33
P (mg)	121	158	119	43
Mg (mg)	16	18	12	4
K (mg)	181	136	152	55
Na (mg)	41	44	58	15
Cl (mg)	150	160	100	60
S (mg)	28	29	32	14
Fe (mg)	0.07	0.08	0.08	0.20
Cu (mg)	0.05	0.04	0.06	0.06
Mn (mg)	0.032	0.007	0.02	0.07
Zn (mg)	0.56	0.57	0.53	0.38
I (mg)	0.022	0.020	0.021	0.007
Se (μg)	1.33	1.00	0.96	1.52
Al (mg)	n.a.	0.05–0.18	n.a.	0.06
Vitamin				
Vitamin A (IU)	185	146	126	190
Vitamin D (IU)	2.3	0.18 μg	2.0	1.4
Thiamine (mg)	0.068	0.08	0.045	0.017
Riboflavin (mg)	0.21	0.376	0.16	0.02
Niacin (mg)	0.27	0.416	0.08	0.17
Pantothenic acid (mg)	0.31	0.408	0.32	0.20
Vitamin B_6 (mg)	0.046	0.08	0.042	0.011
Folic acid (μg)	1.0	5.0	5.0	5.5
Biotin (μg)	1.5	0.93	2.0	0.4
Vitamin B_{12} (μg)	0.065	0.712	0.357	0.03
Vitamin C (mg)	1.29	4.16	0.94	5.00

(Park et al. 2007)

Studies Investigate the Health Advantages of Goat Milk

Animal and human studies have provided significant evidence to suggest that, in comparison to cow's milk, goat milk improves calcium and phosphorous metabolism, zinc and selenium status, and the bioavailability of iron in subjects with anemia. Furthermore, research has also found that undernourished children receiving goat's milk in addition to their recovery diet demonstrated a significant increase in body weight as well as improved fat absorption and protein digestion (Lopez-Aliaga et al., 2010).

Fat & Protein Utilization

Protein and energy malnutrition are serious issues for health care facilities in developing countries, as well as for those suffering from malabsorption diseases. Cow's milk is expensive to produce and not as readily available in developing countries, whereas goat's milk is far more abundant in many areas. The use of this dairy alternative as part of the treatment for malnutrition has been thoroughly investigated. In vitro studies have found a difference in the pattern of digestion of goat milk proteins compared to cow milk proteins. For example, Jasinka (1995) showed that 96% of goat casein was digested completely by trypsin as opposed to cow's casein which was only 76-90% digested. Furthermore, following treatment with human gastric duodenal juice, only a small portion (~23%) of the goat's β-lactoglobulin remained undigested whereas this portion was ~83% in cows (Almaas et al., 2006).

In vivo studies include research conducted in Madegascar involving 30 malnourished children aged 1 to 5 years investigating the effects goat's milk versus cow's milk consumption on their rehabilitation. The children receiving the goat milk in their diet surpassed those on cow milk in weight gain, height, skeletal mineralization and serum contents of vitamin A, calcium, and other minerals, indicating that the utilization of fat and protein was greater in the goat milk group (Razafindrakoto et al., 1994). Similarly, in an Algerian study of 64 infants suffering from malabsorption syndromes, the replacement of cow milk with goat milk in the diet resulted in significantly higher rates of intestinal fat absorption (Haenlein, 2004).

In another study investigating the differences between fat metabolism and use in malabsorption syndrome, researchers observed rats with a resection of 50% of their distal small intestine and control animals (transected). The animals were placed on a goat milk or cow milk diet, and at the end of the trial, the digestive utilization of fat was much higher in the transected and resected groups receiving the goat milk diet. These results of increased efficiency in fat and protein utilization have been attributed to the high levels of medium chain triglycerides, and more soluble protein content present in goat milk (Alferez et al., 2001).

Iron Deficiency Anemia

Studies have shown that calcium rich products, such as dairy, interfere with the absorption of iron. These two minerals depend on the same intestinal transporter (divalent metal transporter-1) for absorption from the gut; therefore a high amount of calcium has an inhibitory effect on the bioavailability of iron. Interestingly, research has also shown that, despite being rich in calcium, goat milk induces a greater nutritive use of iron and minimizes the possible interactions with minerals such as calcium as opposed to animals fed with cow milk. For example, two Spanish studies using rats with iron deficiency anemia investigating the effects of goat milk or cow milk diets on iron status found that after two weeks, the rats following the goat milk diet had improved iron status and increased red blood cell count.

Iron Deficiency Anemia, continued.

The factors that influence the bioavailability of iron in goat milk include the more soluble casein proteins in the milk, which could favour the absorption of iron, as well as the abundance of medium chain triglycerides, which are readily metabolized and absorbed for energy production and increase the synthesis of carrier proteins that result in more iron absorption. Furthermore, the higher amounts of cysteine and lysine in goat milk, which are amino acids known to improve mineral absorption and solubilize iron, respectively, as well as the vitamin C content, which is an important promoter of iron absorption, both contribute to the increased bioavailability of this mineral. It has also been suggested that vitamin A, which is more abundant in goat milk, influences iron metabolism, and a deficiency in this vitamin results in the reduction of transferrin, an iron transporter. Finally, the greater amount of vitamin D in goat milk compared to cow milk is advantageous as it has been suggested that it may favour the absorption of iron by increasing mobilferrin, an iron binding protein (Alferez et al., 2006; Diaz-Castro et al., 2011; Lopez-Aliaga et al., 2000).

Bone Health (Calcium, Magnesium, Phosphorus)

Nutrition plays a key role in bone health, and the benefits of supplementation with calcium and vitamin D in populations at risk of osteoporosis have been well established. However, phosphorous and magnesium are also essential minerals in the maintenance of bone health and prevention of disease. Human and animal studies indicate that goat milk efficiently provides these minerals and therefore contributes to skeletal health (Bonjour et al., 2009).

Earlier studies have shown that goat milk benefits growth and skeletal mineralization in children (Silanikove et al., 2010). Furthermore, greater calcium uptake and higher calcium content in the femur, sternum and longissimus dorsi muscle was observed in rats as a result of goat milk consumption in comparison to cow milk. In addition, goat milk was found to be advantageous over cow milk as no calcium-iron interference was observed in these rats as opposed to those following the cow milk diet. This increased calcium absorption is likely due to the higher vitamin D content of goat milk with respect to cow milk as it is known that vitamin D favors calcium uptake. In addition, the higher content of the amino acid lysine has been found to contribute to greater calcium absorption as this protein is related to calcium transport. Finally, the high amount of medium chain triglycerides also favours the calcium absorption from the intestine (Lopez-Aliaga et al., 2000, Campos et al., 2003).

In cases of individuals suffering from malabsorption, nutrient deficiencies are common, leading to the development of various other diseases including weakened bones. Lopez-Aliaga et al. (2003) studied the nutritive utilization of magnesium in rats with resection of the distal small intestine, in order to mimic the situation of intestinal malabsorption. Consumption of the goat milk diet favoured magnesium storage in bone in both transected (control group) and resected animals compared to the cow milk diet. Research has shown that sufficient casein in the diet increases magnesium intake and retention. As the casein in goat milk is more soluble than in bovine milk, it is more easily absorbed, thereby increasing magnesium uptake. The medium chain triglycerides and vitamin D content of goat milk also favour the absorption and deposit of magnesium in the bones (Lopez-Aliaga et al., 2003).

Bone Health (Calcium, Magnesium, Phosphorus) continued.

Similarly, in another Spanish study investigating the effect of goat milk on the absorption of calcium and phosphorus in rats with intestinal resection also found serum calcium and phosphorus levels, ionic calcium, as well as bone deposit of calcium and phosphorus to be higher among the group given a goat milk diet in comparison to a cow milk diet. As with the uptake of magnesium, the protein and triglyceride composition as well as the vitamin D content of goat's milk influences the deposit of these minerals in target organs among resected and control animals (Campos et al., 2003).

Mineral Bioavailability (Copper, Zinc, Selenium)

In addition to increasing the nutritive uses of iron, calcium, magnesium and phosphorous, goat milk has also been shown to improve the bioavailability of other essential minerals such as copper, zinc and selenium. Copper is an important nutrient needed for the function of enzymes, and electron transporters. In particular, this mineral is a fundamental component of cytochrome c oxidase, which is an enzyme that is involved with the generation of ATP energy in the body. Similarly, zinc plays an important role in biochemical reactions as well as DNA and RNA stabilization, and selenium is an essential component of anti-oxidative enzymes in the body for the protection against cell damage.

Researchers at the University of Granada found that the nutritional characteristics of goat milk increased the bioavailability of copper, zinc and selenium in comparison to a cow milk diet and a non-milk diet in both normal and resected rats. In addition to the higher vitamin C and D content as well as medium chain triglycerides, which help with mineral absorption, the higher levels of cysteine in goat milk also create an advantage for zinc and selenium uptake. Zinc is transported through the brush border membrane of the intestine via a peptide transport system including a cysteine-rich intestinal protein. Similarly, the biologically active form of selenium is selenocysteine, thus an increased supply of this amino acid could favour the utilization of the mineral in the body (Alferez et al., 2001; Barrionuevo et al., 2003; Lopez-Aliaga et al., 2000).

Superior Nutrient Absorption

The unique macro- and micronutrient composition of goat milk has been recognized for its superior digestive and absorptive qualities, and the vast majority of human and animal studies have confirmed that goat milk is different in character to cow milk, in regard to fatty acid, protein and mineral utilization. Goat milk can be an excellent natural food alternative, especially in cases of malabsorption syndrome or malnutrition.

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