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Review

Functional Properties of Goats' Milk: A Review

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The growing awareness of the relationship between diet and health has led to increased demand for food products that support health beyond providing basic nutrition. Demand for *caprine* milk has been rising steadily due to its good nutritional value and the possibility that it confers physiological benefits. While dairy products in general provide health benefits, research has shown that goats milk confer more functional benefits than any other milk. The milk fats and protein molecules have structures that facilitate high bioavailability and absorbability which contribute significantly to the nutritional requirements of man. The milk contains physiologically bioactive compounds like free amino acids, polyamines, medium chain fatty acids, oligosaccharides and trace minerals which help to boost the immune system and mitigate occurrence of certain diseases. Clinical trials have shown that nutraceuticals derived from goats' milk proteins have potential to correct metabolic syndromes, lower cardiovascular disorders and mitigate onset of various terminal diseases. Due to low incidences of allergenic reactions production of infant formulas from goats milk has grown significantly replacing cow and soy formulas in most developed countries.

Key words: Functional foods, Bioactive components, Nutritional benefits, Physiological benefits

INTRODUCTION

The demand for functional foods has been rising steadily over the last few years. Functional foods are those foods which provide health benefits beyond the normal nutritional requirements. These foods contain physiologically-active food components (Hasler, 1998). Traditionally all foods were thought to be functional on the basis of their nutritive value. However, the term "functional" as it applies to food has nowadays adopted a different meaning - that of providing an additional physiological benefit. More significant is their potential to mitigate diseases, promote health, and reduce health care costs.

Dairy products belong to this category of functional foods. They contain nutrients which aid in preventing occurrence or development of certain diseases to critical levels where they can cause death. In recognition of the role dairy products play in human health, the American National Academy of Sciences has recommended use of dairy products for most age groups with more focus being on probiotics (Fuller, 1998).

The effect of fermented milks was discovered more than 40 years ago in studies conducted among the Maasai people in East Africa. Consumption of high amounts of fermented whole milk (4 – 5 litres per day), the Maasai were found to have low levels of serum cholesterol and low incidences of clinical coronary heart disease despite living on a diet rich in meat.

While dairy products in general confer functional benefits to the body, goat's milk has specifically been singled out as conferring more functional benefits compared to milks from other dairy animals.

FUNCTIONAL BENEFITS OF GOATS MILK

Nutritional benefits

Provision of nutrients is the most important factor in any functional food.

Source of nutrients and bioactive components

Goats milk is a good source of nutrients important for people of all ages. The milk provides high quality protein, fat (including essential fatty acids- MCT), various vitamins, minerals (including calcium, phosphorus and

iodine) and lactose. Along with lactose it contains other carbohydrates, such as nucleotide sugars, glycolipids, glycoproteins and oligosaccharides.

Goats' milk contains bioactive components such as polyamines, nucleotide sugars, free amino acids, medium chain fatty acids, polyunsaturated fatty acids and serum proteins (Haenlein, 2004; Rampilli *et al*., 2004). It is also characterized by high bioavailability of proteins, carbohydrates, fats, minerals and vitamins. Studies has also shown increased bioavailability of copper, zinc, selenium and iron from goats milk (Campos *et al.* 2004; Haenlein 2004; Alferez *et al..* 2003; Barrionuevo *et al.* 2003).

These components are often present in goat milk at levels similar to human milk making it a better alternative for production of infant formulae.

Bioavailability of nutrients

The nutrients are contained in fairly good proportions, well balanced and readily available to meet human body requirements. Availability of proteins is higher than in milk from other animals. Provides 8.7 grams of protein (17.4% of the daily value for protein) per 100 gm. While same amount of cow milk provides 8.1 grams (16.3% of the daily value for protein). Although the mineral content of goat's milk is generally similar to the cows, goat's milk contains 13 percent more calcium, 25 percent more vitamin B-6, 47 percent more vitamin A, 134 percent more potassium. It has three times more niacin. It contains four times more copper and 27 percent more selenium

Enhanced digestibility and micronutrient absorption

Digestibility of goats' milk is highly enhanced by nature of the proteins and the fat molecules. Protein molecules are thinner and fat molecules have more fragile membranes. The increased digestibility of protein is of more importance to infants, invalids and convalescent diets.

The milk has a low curd tension of 36g, cow range between 15-200g, average at 70 g. Goats milk range between 10-70g, average at 36g.

Curd tension is the measure of the hardness or softness of the curd. Due to low curd tension the milk is easily digested. Low curd tension is attributed to low levels of alpha-S1 casein and higher levels of A_2 beta-casein.

Hydrolysis of casein in the stomach is better at 96% compared to 76-90% of cow milk casein while human casein is completely hydrolyzed (Jasinka 1995). Goat milk will digest in a baby's stomach in 20 minutes, whereas cow's milk take 2-3 hours (Attaie et al., 2000). In terms of digestibility and nutrient absorption, it is a better substitute for breast feeding.

Goat milk contains more of the essential fatty acids (linoleic and arachidonic). It has a greater percentage of medium and short chain saturated fatty acids like glycerol ethers. These are important for the nutrition of the infants. Their ester linkages are more readily hydrolyzed enabling rapid digestion and absorption.

Goats' milk is naturally homogenized. It does not contain agglutinin which aids in clustering of fat globules leading to creaming. Dispersed fat globules are easier to digest and absorb.

Compared to cow, goat milk contains twice the content of medium chain fatty acids, such as caprylic and capric acids (C_8 & C_{10}). These medium chain fatty acids provide energy needed during metabolism.

The high levels of medium chain triacylglycerols (MCT) and amino acids cysteine and lysine facilitates the increased absorption of iron. Absorption of micronutrients like iron, phosphorus, calcium, copper, zinc, selenium and magnesium is more efficient than from any other milk (Alferez et al., 2003; Campos et al., 2003; Lopez-Aliaga et al., 2003, Barrionuevo et al., 2002). Studies have also shown that anaemic rats fed on goat milk have a higher liver weights and efficiency of haemoglobin regeneration than those given cow milk.

Calcium is widely recognized for its role in maintaining the strength and density of bones in a process known as bone mineralization. Calcium and phosphorous join to form calcium phosphate. Calcium phosphate is a major component of the mineral complex - hydroxyapatite that gives structure and strength to bones. 200ml of goat's milk supplies 32.6% of the daily value (DV) for calcium along with 27.0% of the DV for phosphorus while 200ml of cow's milk provides 29.7% of the DV for calcium and 23.2% of the DV for phosphorus.

In a study to determine the effect of calcium, Finnish researchers' enrolled 195 healthy girls aged 10-12 years and divided them into 4 groups. One group was given supplemental calcium (1000 mg) + vitamin D3 (200IU) each day. The second group received only supplemental calcium (1000 mg/day). The third group ate goat cheese supplying 1000 mg of calcium, and the fourth group was given a placebo supplement. At the beginning and end of the study, DEXA (Dual-Energy X-ray Absorptiometry) scans were run to check bone indexes of the hip, spine and the whole body. Tibia was checked by peripheral quantitative computed tomography.

Girls getting their calcium from cheese had higher whole-body bone mineral density and cortical thickness of the tibia than girls given supplemental calcium + vitamin D, supplemental calcium alone, or placebo. While the researchers noted that differences in the rate at which different children naturally grow might account for some of the differences seen in bone mineral density, they concluded that increased calcium intake from goats cheese appears to be more beneficial for cortical bone mass accrual than the consumption of supplement tablets containing a similar amount of calcium.

Aliaga *et al*. (2000) compared the influence of goat and cow milk on digestion and utilisation of calcium in rats. They found that goat milk enhanced calcium content of femur, sternum and Longissimus dorsi muscle better than cow milk.

Goats milk has easier and enhanced digestion and absorption of lactose and lactose derived oligosaccharides. This is important for subjects with compromised intestinal function (intestinal bowel syndrome)

Physiological benefits

Reduces the chances of contracting type-1 diabetes

Goat milk contains A_2 Beta-Casein, while cows milk contain A_1 Beta-Casein. Protein A_1 beta casein has been cited as a trigger for type 1 diabetes (Elliott et al., 1999)

Inhibition of pathogens by prebiotic oligosaccharides

Prebiotics are non-digestible food ingredients that have the potential to benefit the host by selectively stimulating the growth of desired organisms in the GI- tract of the host. Goats milk like the human milk contains oligosaccharides which act as prebiotics. These are important to the infants and also the elderly. Clinical trials have shown that several different oligosaccharides can be used to stimulate bifidobacteria in the GI- tract. These include inulin, fructo-oligosaccharides (FOS), galactooligosaccharide and lactulose. Studies have shown that oligosaccharides derived from goats milk have the potential, when included in infant formula, to stimulate host bifidobacteria to grow to levels similar to those in the GI tracts of breast-fed babies. Milk oligosaccharides are beneficial to the infant with regard to their prebiotic and anti-infective properties. Goats' milk oligosaccharides particularly 6-sialyl lactose constitute the"soluble fibre" which provides nutrients for colonic bacteria. These oligosaccharides provide substrate needed by health enhancing bacteria to multiply in the gut (McVeagh et al., 1997).

Goats' milk oligosaccharides are anti-inflammatory. They have been shown to inhibit the adhesion of bacteria to the epithelial membrane, reduce translocation of harmful bacteria in the epithelial cells and promote the selective growth of lactobacillus and bifido bacteria. They act as pathogen receptors by enabling specific interactions between them and pathogens.

This way the intestinal mucosa is protected against infection. This interaction inhibits pathogens such as *Campylobacter jejuni*, *Streptococcus pneumonia*, enteropathogenic *Escherichia coli* and neutralizes effects of *Escherichia coli* toxin (Newburg, 1999; Hirmo et al., 1998).

Galactose is a major component of some very important brain lipids including myelin and it has been elucidated that galactose derived oligosaccharides play a role in neonatal brain development (Kunz et al., 1999)

The oligosaccharide level found in goat milk is about 250 - 300 mg per litre of milk which represents 10 times more than oligosaccharides reported in other commercial milks.

Goat milk soothes the digestive tract

Goat milk has better buffering ability than over-the-counter antacids. It has been used and recommended as a supplement to reduce indigestion by nutritionists. It helps soothe irritated areas in the stomach and intestines. Buffering capability of the milk is ideal for treatment of gastric ulcers and also minimizes discomfort resulting from digestive disorders.

Alkalinizes the blood and the intestine

Goat milk helps to increase the pH of the blood stream. It is the only dairy product with the highest amount of the amino acid L-glutamine an alkalinizing amino acid. Acidic blood and low intestinal pH levels have been associated with fatigue, headaches, muscle aches and blood sugar imbalances.

Prevention of cancer and rheumatoid arthritis

High levels of calcium help protect colon cells from cancer-causing chemicals, prevent the bone loss that can occur as a result of menopause or certain conditions such as rheumatoid arthritis.

Prevent obesity

High calcium levels helps in the oxidation of fat. This has been shown by a study published in the American Journal of Clinical Nutrition by Playford et al (2000).

Normal weight women aged 18-30 years were randomly assigned to a low (less than 800 mg per day) or high (1000-1400 mg per day) calcium diet for 1 year, and the rate at which their bodies burned fat after a meal was assessed at the beginning and end of the study.

After 1year, fat oxidation was 20 times higher in women eating the high calcium diet compared to those in the low-calcium control group. The blood levels of parathyroid hormone were checked and found to correlate with their rate of fat oxidation. More calcium in the body keeps the blood levels of the parathyroid hormone low. When there is low rate of fat oxidation due to low calcium level,

parathyroid is secreted to instruct the bone cells to release calcium to the blood stream.

Goats milk has more of the short and medium chain triacylglycerols (MCT). MCT up to C_{14}, are not incorporated into body lipids as is the case with the longer chain fatty acids. That way goats milk does not significantly contribute to obesity and other related heart problems.

Medium chain fatty acids (MCFA) have a unique ability to lower, inhibit and dissolve cholesterol deposits.

Antimicrobial activity

Goat milk contains high levels of medium chain fatty acids, such as caprylic and capric acids (C_8 & C_{10}). These fatty acids are highly antimicrobial. Capric and caprylic acids are used in dietary supplements to inhibit the growth of *Candida albicans* and other yeast species.

Boosts immune system

Studies have shown that of all the milks goat milk is the highest source of selenium. It contains more than 2.5 times the selenium in powdered infant formula (19.98 mg/l vs. 7.47 mg/l) and nearly 35% more than pasteurized cow milk (19.98 mg/l vs. 14.85 mg/l). Goat milk is also richer in selenium than human milk, which contains 15.69 mg/l. (Rodriguez, Sanz Alaejos, M. Diaz Romero, 1999).

The mineral selenium is important in the modulation of immune system. It also has antioxidant properties. In most cases it is deficient in the human body and has to be provided in the diet. Deficiency has been linked to rapid progression of HIV/AIDS and other viral diseases. Selenium in the body works in two ways. It helps to control the human immune system, upgrading it when necessary, and downgrading it when it is overactive. Selenium also works directly on viruses by preventing them from replicating. It also improves T lymphocyte cell function and modulates the production of interleukin, an important components of the immune system.

Prevents build up of cholesterol level in blood

Goats milk is Naturally homogenization. The smaller size of fat globules provides a better dispersion, and a more homogeneous mixture of fat in the milk. Research indicates that there is more involved to the creaming ability of milk than mere physical size of the fat globules. Agglutinin which lacks in goats milk has been found to favour clustering of fat globules. To prevent clustering of fat globules, milk is homogenized (as it happens with cow's milk). When fat globules are broken an enzyme associated with milk fat, known as xanthine oxidase become free. The enzyme is not destroyed by low pasteurization temperatures employed on fresh milks. When such milks are consumed the enzyme penetrates the intestinal wall and enter the blood stream. Once in the blood it is capable of creating scars to the heart and arteries. This in turn stimulates the body to release cholesterol into the blood in an attempt to provide a protective fatty material on the scarred areas leading to arteriosclerosis. In goats milk, fat globules are not homogenized. The enzyme is bound to the globule membrane and digested with the other milk components.

Less allergenic as an infant formula

In most developed countries the goat milk is specifically marketed for the infant formula. In the USA and Canada the department of pediatrics has recommended that cows milk be avoided for children between 0-6 months due incidences of allergy (Playford et al., 2000). The allergenic problems common with infants fed on cow milk is rarely encountered when the formula is produced with goat milk destroyed by low pasteurization temperatures employed on fresh milks. When such milks are consumed the enzyme penetrates the intestinal wall and enter the blood stream. Once in the blood it is capable of creating scars to the heart and arteries. This in turn stimulates the body to release cholesterol into the blood in an attempt to provide a protective fatty material on the scarred areas leading to arteriosclerosis. In goats milk, fat globules are not homogenized. The enzyme is bound to the globule membrane and digested with the other milk components.

Goat's milk contains only trace amounts of alpha-S1, an allergenic casein protein, found in cow's milk. Another factor that causes allergenic reactions is resistance of proteins to digestion. Beta-lactoglobulin is the protein most resistant to digestion. Whereas Goat milk contains similar levels of beta-Lactoglobulin as the cows milk, the beta-Lactoglobulin present in goat milk is absorbed more readily leaving less intact beta-Lactoglobulin in the intestine to cause an allergic reaction.

Allergenic effects are characterized by Gastrointestinal disturbances, vomiting, colic, diarrhea, constipation and respiratory problems in infants. Regular intake of goat milk by the infants improves mineralization of skeleton, increases blood serum vitamin, mineral and haemoglobin levels.

DNA replication and neurogenesis in infants

Milk contains nucleotides, free amino acids and polyamines that have important functional benefits to the infants. Research has shown that goat milk contains higher levels of these compounds, requiring much lower supplementation compared to cow milk. Children require a constant supply of DNA and a rapid turnover of RNA to

Table 1. Levels of nucleotides, free amino acids and polyamines in goats milk.

Component	Level in goat milk	Supplementation required
Total nucleotide monophosphate	6.6 u mol /100ml	none
Taurine	7.5 mg/100ml	some
Total polyamines	51 ug /100ml	none

grow strong and health. Millions of new cells need to be produced every day to sustain growth. Rapid growth increases the daily requirement of nucleotides (Table 1).

Growth factors for infants

Goats milk contains high levels of growth factors similar to those found in human milk making it an essential diet for the infants. The Transforming Growth Factor-a (TGF-a), has a physiological role in maintaining regular functionality of the infant. (Playford et al., 2000).

The Transforming Growth Factor-ß (TGF-ß), is involved in numerous processes, such as the development and differentiation of the intestinal epithelium, regulation of the immune response system where it is involved in production and induction of oral tolerance (Kalliomaki et al., 2000).

Neuropeptides, such as neurotensine, Somatostatin, and vasoactive peptide foster immunity response by stimulating T lymphocyte cells and activating macrophages (Goldman et al., 2000).

Antioxidation of radicals in the body

Riboflavin's is a cofactor for the enzyme glutathione reductase that reduces oxidized form of glutathione to the reduced form which is less reactive. This way the mitochondria is protected from damage. Reduced glutathione acts as an antioxidant.

Riboflavin is a B vitamin important for energy production. Riboflavin (vitamin B2) plays two important roles in the body's energy production. When active in energy production pathways, it takes the form of Flavin Adenine Dinucleotide (FAD) or flavin mononucleotide (FMN). In these forms, riboflavin attaches to protein enzymes called flavoproteins that allow oxygen-based energy production to occur. This is important for vital organs such as heart and liver

Goats milk as a neutraceutical

Nutraceuticals are food components that have been isolated and purified. They are sold in medicinal forms to provide physiological benefits against diseases. Goats milk proteins and other components are currently being used to produce nutraceuticals. Isolated peptides relax blood vessels in people suffering from high blood pressure. Lactotripeptide present in normal milk protein is inactive but when isolated has been found to effectively deal with high blood pressure.

Clinical trials have also found hydrolysed casein to be effective in management of high blood pressure. Hypertension is a major controllable risk factor associated with cardiovascular disease (CVD) events such as myocardial infarction, stroke, heart failure and end-stage diabetes. The renin-angiotensin-aldosterone system is a target for blood pressure control. Cleavage of angiotensinogen by renin produces angiotensin-I which is subsequently hydrolyzed by angiotensin-I-converting enzyme (ACE) to angiotensin-II a potent vasoconstrictor (causes hypertension). Various side effects have been associated with the use of ACE inhibitory drugs in the control of blood pressure. These include hypotension, increased potassium levels and reduced renal function. Goats' milk proteins, both caseins and whey proteins, are a rich source of ACE inhibitory peptides. The derived peptides have not been associated with statistically significant hypotensive effects or changes in potassium and renal function.

Other isolated protein components are being used to prevent and manage metabolic syndrome - a condition characterized by obesity and disturbed glucose metabolism. Therapeutic proteins have been isolated in transgenic goats. A genetic construct of human antithrombin gene is inserted into the transgenic goats under control of beta casein promoter. The milk proteins isolated have been found to help patients with congenital antithrombin problem.

Peptides from goats beta casein have immune stimulating properties. Isolation and concentration of beta casein from goat milk is better than from cow milk using the same solvents and extraction conditions making extraction more economical.

LIMITATIONS OF GOATS MILK

Low in folic acid

Goats milk contains virtually no folic acid. To be adequate as an infant formula it has to be fortified. Lack of folic acid has been linked to congenital defects such as malformation of spinal cord associated with siemese twins.

Goats milk is an apocrine secretion

Apocrine is a type of glandular secretion where the secreting cell is released along with the milk. Cow secretion is alveolar merocrine secretion the cells remain undamaged during secretion. This type of secretion produces milk with high levels of cytoplasmic debris and epithelial cells. The milk has high levels of somatic cell counts which are not desirable.

Risk of prostrate cancer

Milk from transgenic goats' milk has high amounts of Insulin – like Growth Factor-1(IGF-1). This has been reported as a potential risk factor in prostrate cancer.

CURRENT TRENDS

Goats milk formulas are currently replacing cows milk and soy formulas as an alternative for infant diets. The milk is being promoted as an essential diet for invalids, convalescent, infants and the immune -compromised. Due to high digestibility and absorption rates the milk is being used in many developing countries as a source of nutrients to patients with full blown AIDS, which in most cases is characterized by intestinal disorders which affect digestion.

In developed countries more focus is geared towards production of nutraceuticals from goats milk.

SUMMARY AND RECOMMENDATIONS

The need for improved nutrition and functional benefits has a significant impact on the continuing growth of the goat milk industry.

More research is needed to give conclusive evidence on physiological and nutritional benefits, particularly the effects of goats' milk on promotion of immune systems. Whereas cow and human milk components have been sequenced and characterized, more research needs to be done to give direction on the role of specific goats milk components in mitigating diseases and preventing allergies.

CONCLUSION

Confirmation of health benefits is not a simple task. It needs conceptual process and product development, validation, efficacy analysis and clinical studies. The biological markers of either health improvement or disease risk-reduction are not unanimously recog-nized. Health involves many complex and interactive functions. It is usually rare to find uncomplicated mechanisms that involve simple molecules acting in isolation. For the food industry to claim physiological functions of certain foods, it must have quantifiable indicators of bioactive molecules and interaction that controls biological functions related to physiology.

As the world populations expand with more competition for land areas, milk production from goats is bound to increase significantly. Economically, there are more returns from goats milk per unit quantity than from milks of other commercial animals. The cost of general management and feeding of dairy goat is very low. The milk is also being used to produce high value products like nutraceuticals.

Due to its high nutritive value and physiological properties, goats milk should be promoted in the developing countries, where malnutrition and diseases are more prevalent and the cost of healthcare is prohibitive due to high poverty levels.

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