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Implications of Nutrigenomics in the Feeding of Goats and its Impact in Functional Properties of Goat's Milk: A Review

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ABSTRACT

The feeding of ruminants such as goats is critical because conferring nutraceutical characteristics to the milk. Alfalfa is forage used for feeding ruminants and depending on plant growth conditions, it will impact animal production. The production of goat's milk has increased in recent years, the goat's milk and its derivatives are relevant because of the quality and quantity of their proteins, carbohydrates, fats, vitamins and minerals. Goat's milk degrades significantly faster and has lower allergenicity than cow's milk. Their fat composition reinforces those essential characteristics of goat's milk. Goat's milk has a higher concentration of caproic acid, caprylic acid, capric acid, palmitic acid, omega-3 linolenic acid and low content of long-chain fatty acids as stearic acids than cow's milk and this indicates that the goat´s milk can be more easily attacked by digestive enzymes and high efficiency in lipid metabolism compared to cow´s milk. This review discusses the impact of the feeding system on the nutrimental and functional characteristics of goat's milk.

Key words: Bioactivity, Forage, Nutraceutical, Ruminants.

Milk is a liquid mixture of water, protein, lactose, vitamins and minerals secreted by the mammary glands (Alais, 1971; Agudelo and Bedolla, 2005). Goat's milk is the third most produced worldwide, after cow's and buffalo's milk. Approximately 81% of milk production in the world derives from cattle, followed by milk from other species, such as buffalo (15%). At the same time, goats, sheep and camels contribute to about 4% of total milk production (FAO, 2019). However, the milk production of small ruminants, including sheep and goats, has grown in recent years, seeking new consumer markets (Selvaggi *et al.*, 2014a). In addition, milk production doubled in the last decade and could increase up to 53% by 2030 (Pulina *et al.*, 2018). In turn, the cost of maintenance and feeding goats is meager, but the marketing and use of goats are still limited in developing countries (Kumar *et al.*, 2016). Goat's milk and its derivatives are gaining interest due to its quality and quantity, its proteins, carbohydrates, fats, vitamins and minerals and its functional properties (Albenzio *et al.*, 2016).

Protein is a precursor characteristic of many human health benefits in goat's milk. The percentage of protein in goat's milk is similar to cow's milk; however, some differences come from their constituents, such as casein content and structure of the casein micelle, bioactive peptides and the profile of the amino acids, nucleotides and nucleoside (Kumar *et al.*, 2016). Another characteristic of the goat's milk is the content of nutraceuticals such as phenolic compounds; this nutrient helps consumers' health and hence proper and adequate feeding of the goat can modify its quantity (Chávez-Servín *et al.*, 2018).

The feeding systems for ruminants such as goats have been found to affect the composition of goat milk and can influence antioxidant activity and nutraceuticals compounds (Keles *et al.*, 2017, Zazharska *et al.*, 2018). Other factors affecting milk composition are the growing season and cutting time of forages and grasses (Di *et al.*, 2015). This review aims to show the impact of the feeding system on the nutritional and functional characteristics of goat's milk, as well as on the advantages of goat's milk as a potentially available product and its benefits to human health. This work was done from 2020 to 2021 at the Engineering Faculty of the Amazcala Campus of the Autonomous University of Querétaro (UAQ) México.

Implications of nutrigenomics

Use of forages on the ruminants feeding

Forages are essential in ruminant diets (cows, goats and sheep); legumes are the most important. The legumes are

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consumed in quantities about 20 per cent greater than grasses because the legumes contain fewer cell walls (Rojas *et al*., 2019). The cell wall quantity in forages determines the rate of digestion and intake in ruminants. The leaves are more easily broken down than stems in the plant because of their cell walls (lignin quantity). The lignification in legumes and grasses is different; in grasses, the lignin is more widely distributed in the plant and it has a more significant inhibitory effect on the rate of digestion. In legumes such as alfalfa, the lignin and protein quantity depends on the cutting time of the plant (McDonald *et al*., 2010).

One good example of forage is the genus *Medicago* which belongs to the legume subfamily as alfalfa (Gholani *et al*., 2014). Alfalfa is the fourth crop with the highest economic value in North America after corn, soy and wheat. It is the most important crop of forage utilized in ruminant feeding globally (Mielmann, 2013). Many factors, such as the harvest period, influence alfalfa´s nutritionally. Cutting the alfalfa in an optimal growth state can improve the crop's fields and quality (Yari *et al*., 2012). A decrease of crude protein (PC) and an increase in fiber has been reported according to the maturity states (Lamb *et al*., 2003). Alfalfa proteins are mainly located in chloroplasts and the change from vegetative growth to reproductive growth increases nutrient production and decreases crude protein content (Lamb *et al*., 2012). The protein is related to L-glutamic acid and glutamine content; they are precursors of several amino acids, purines and pyrimidines. L-glutamic acid and glutamine content in mid-flowering alfalfa are significantly lower than in the outbreak period; this is vital for cutting alfalfa for ruminant feeding (Bezerra *et al*., 2016).

The rumination and fermentation processes are fundamental in ruminant animals such as goats. These are relatively slow processes and fibrous foods (cell wall resistance) may take a long time in the digestive tract to extract their digestible components. Reducing lignin content in forages can improve digestibility and animal performance (Barros *et al*., 2019).

Impact of forage on the quality of Goat's milk

The feeding system using free-range grazing or permanent confinement has affected the composition of goat's milk. It may influence the antioxidant activity not only in the milk but also in milk products (Keles *et al*., 2017). An additional factor affecting the composition is the year's season, rainy or dry (Hilario *et al*., 2010; Di *et al*., 2015). Kuhnen *et al*. (2014) found that the amount of phenolic compounds in milk samples differs among year's seasons of the year due to the differences in the botanical composition of ingested forages, diversity of plant species and pastures in each season. Di *et al*. (2015) show that the consumption of fresh forage diets provides an antioxidant effect in the products elaborated with goat's milk due to the role of phenolic compounds that directly impact antioxidant activity in milk.

The modification in the composition of feeding has repercussions on milk design. Increasing the proportion of forage in goat's feeding, the quantity of protein is higher and the fat lower (Khaskheli *et al*., 2020). The animals can consume unsaturated fatty acid to increase the synthesis of fatty acid of Novo in the mammary gland. A study on feeding goats and sheep with spring and summer forage had significant content of linoleic acid concerning autumn and winter (Fernández *et al*., 2006).

Goat's feeding and its impact on milk flavor

Goat's milk flavor is a characteristic of lower lipolysis and is responsible for rancidity (Chilliard *et al*., 2003). One possibility to attack the flavor aspect is employing lipid supplementation in the diet to increase the ruminant's consumption of energy of high interest in the first lactation, increasing milk production and limiting the mobilization of the body lipids (Chilliard and Bocquier, 1993). Furthermore, the goat's milk lipolytic system and medium-chain fatty acids could significantly change the content of free fatty acids, playing a significant role in the occurrence of the characteristic goat flavor (Chilliard *et al*., 2003).

Fat supplementation in diets could improve goat's milk composition for greater control of cheese processing and satisfaction of consumer demand. Still, the results show positive or adverse changes in goat dairy products' physical characteristics and nutritional or dietetic properties (Chilliard *et al*., 2003). The addition of flavors carries out the development of new products from goat's milk; aromas using essences and fruits can modify its taste and contribute to its nutritional value (Machado *et al*., 2017).

Goat's milk and its nutritional and functional properties

In 2016, the United Nations Food and Agriculture Organization (FAO) reported approximately 1 billion goats worldwide, with 15.2 million tons of milk. The significant producers of goat's milk are India, Bangladesh and Pakistan in Asia; Sudan, South Sudan and Somalia in Africa; France, Spain and Greece are the leading Europe producers (FAO, 2019).

Cow's milk is the most consumed worldwide (Kumar *et al*., 2016). There is a noticeable difference in fat and protein between cow´s and goat's milk. The fat content is 4.2% in cow's milk and 3.8% in goat's milk (Ahmad *et al*., 2013). The casein protein micelles' size ranged from 100 to 200 nanometers (nm) in goat's milk and from 60 to 80 nanometers (nm) cow's milk (Silanikove *et al*., 2010). The size of the protein micelles makes a marked difference in their sedimentation rate, solubilization and heat stability (Haenlein, 2004). These characteristics are essential for making sub-products with goat's milk as a different cheese or yogurt.

Bioactivity of Goat's milk-derived peptides

The proteins of goat's milk are essential nutrients that should be present in diets for infants and young's children (FAO, 2019). An *in vitro* study using gastric and duodenal juices demonstrated that goat's milk proteins degraded faster than cow's milk proteins. This characteristic represents an advantage for digestibility as suggested by Albenzio *et al*. (2012). The whey proteins such as a-lactoalbumin, β-lactoglobulin, albumin and Lactoferrin are less susceptible to gastric digestion and enter the intestinal tract as intact protein, where they carry out their biological functions (Inglingstad *et al*., 2010) as antimicrobial action (Liu and Newburg, 2013), cognitive development (Timby *et al*., 2014) and immune modulation in the neonate (Donovan, 2016).

Most bioactive peptides derived from goat's milk had antimicrobial, antihypertensive, antioxidant and opioid (agonist and antagonist) functionalities. Six peptides have been identified from b-casein (antimicrobial; ACE-inhibitory, immunomodulatory; anti-thrombin), two from as1-CN (antimicrobial; ACE-inhibitory), one from as2-CN (antimicrobial; ACE-inhibitory) and k-CN (antimicrobial) (Liu and Newburg, 2013). Low numbers of b-Lactoglobulin (b-Lg) peptides (ranging from 0-1.2%) have been found in cow and goat's milk because b-Lg is resistant to pepsin (Hodgkinson *et al*., 2019).

Other peptides released in the β-casein hydrolysis are the tripeptides inhibiting the angiotensin-converting enzyme (ACE), which has the following amino acid sequence: Valine-proline-proline (VPP) and Isoleucine-Proline-Proline (IPP) and they found in goat's milk or derived products such as cheese, which show cardiovascular and antihypertensive activity (Murray and Fitz-Gerald, 2007; Ricci *et al*., 2010). These peptides are enormously increased by tripeptides hydrophobic chains with aromatic or branched amino acids (Ricci *et al*., 2010). Pihlanto-Leppälä *et al*., 1998 demonstrated that the fermentation of milk with cell crops is not enough to generate the tripeptide of ACE. Digestion with pepsin and trypsin could be necessary. The last explains what can happen under *in vivo* conditions or the gastrointestinal tract when fermented products are ingested and generate bioactive peptides.

Gastric and duodenal enzymes degrade goat's milk proteins faster and more efficiently than camel, cow and sheep milk (Tagliazucchi *et al*., 2018). Almaas *et al*., 2006 found that goat's milk protein degrades faster than cow milk using human gastrointestinal proteolytic enzymes. Espejo-Carpio *et al*., (2013) reported an increase in the digestibility of goat's milk proteins as a function of the enzyme-to-substrate ratio. The digestibility of the goat's milk will be more rapid than in other types of milk and benefit the consumer's health.

β-casein, another type of casein, is more frequent in goat's milk, representing between 48-60% of total caseins (Potocnik *et al*., 2011). The polymorphic variants of β-casein from the most common dairy cattle breeds are A1, A2 and B. The amino acid at position 67 of the β-casein sequence is critical for releasing β-casomorphin-7. β-casomorphin-7 (BCM-7) is a peptide released by the hydrolytic action of β-casein, associated with a genetic variant related to the breed of goats and cows. In variant A2, the hydrolysis of Isoleucine 66-Proline 67 does not occur or is performed in a low range. For variant A1, the release of BCM-7 is generated by pepsin's action. Goat's milk tends to b-casein A2 because the amino acid 67 is a Proline and not developed BCM-7 (De Noni *et al*., 2009, Muñoz-Salinas *et al*., 2022).

Nutraceutical characteristics of goat's milk

In milk and goat cheese, endogenous antioxidants of proteinic origin, such as Lactoferrin and exogenous antioxidants, such as vitamins A, E and C. (Raynal-Ljutovac *et al*., 2008). Goat's milk contains more vitamin A (2,074 IU) than cow's milk (1,560 IU) due to goats turning all carotene into vitamin A, which is why it's whiter than cow's milk. Additionally, goat's milk is a rich source of riboflavin that acts as a growth factor and has 350% more niacin than cow's milk (Pfeuffer, 2000).

The phenolic compounds in foods showed their benefits by reducing pathogenesis or the severity of chronic diseases, including cardiovascular diseases (Redan *et al*., 2016). So far, the phenolic compound content in goat's milk and dairy products like cheese and whey has been little studied (Hilario *et al*., 2010). The ruminant's milk has higher conjugated linoleic acid (CLA) than non-ruminants; this anticancerigen acid decreases atherosclerosis (Pfeuffer, 2000). The content of CLA is significant when feeding goat with grasses (Fernández *et al*., 2006, Kumar *et al*., 2016).

The oligosaccharides present in milk can act as prebiotics, which helps to maintain the gastrointestinal tract healthy by promoting the growth of beneficial bacteria and preventing the development of pathogenic bacteria. More than 95% of oligosaccharides in human milk are resistant to digestion and used by intestinal bacteria. The oligosaccharides from goat's milk share a similar structure to human milk (Urashima *et al*., 2013). Goat's milk contains between 250 to 300 mg/L oligosaccharides, 4 or 5 times higher than cow's milk (Martínez-Ferez *et al*., 2005). The goat's milk showed higher levels of mannose-6-phosphate. It participated in the glycolytic pathway and was implicated in synthesizing oligosaccharides, biosynthesis of glycoproteins and glycophospholipids (Kalhan, 2009).

Selenium plays a cofactor in the activity of glutathione peroxidase. It prevents lipid peroxidation in mammals (Crespo *et al*., 1995) and has a protective effect on events such as atherogenicity (Wojcicki *et al*., 1991). In human, goat and camel's milk, selenium is about 50% higher than cow's milk (Debski *et al*., 1987). Higher selenium content could be because the goat's and camel's milk improves oxidative stress in experimental type-I diabetic rats (Meena *et al*., 2015).

CONCLUSION

Goat's milk and its derivatives have functional characteristics that are good for the consumer. The most relevant are: the quality and quantity of their proteins, which can be consumed by people with intolerance to cow's milk or digestive disorders; Goat's milk has low allergenicity. The milk composition is influenced by the food consumed by the Goat, as its character is nutraceutical and functional. The feeding of the goats, housing and climate can affect the milk nutraceutical power. The nutritional characteristics of goat's milk give this food its value and, at the same time, allow us to continue investigating its peculiarities to encourage greater consumption and production of goat's milk and derivatives products with valor functional.

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Conflict of interest

The authors declare no conflict of interest.

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