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Recent Advances in the Valorization of Goat Milk: Nutritional Properties and Production Sustainability

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Abstract**—**Goat dairy products are gaining popularity worldwide. In developing countries, but also in many marginal regions of the Mediterranean area, goats represent a great part of the economy and ensure food security. In fact, these small ruminants are able to convert efficiently poor weedy plants and small trees into traditional products of high nutritional quality, showing great resilience to different climatic and environmental conditions. In developed countries, goat milk is appreciated for the presence of health-promoting compounds, bioactive compounds such as conjugated linoleic acids, oligosaccharides, sphingolipids and polyammines. This paper focuses on the recent advances in literature on the nutritional properties of goat milk and on innovative techniques to improve its quality as to become a promising functional food. The environmental sustainability of different methodologies of production has also been examined. Goat milk is valued today as a food of high nutritional value and functional properties as well as small environmental footprint. It is widely consumed in many countries due to high nutritional value, lower allergenic potential, and better digestibility when compared to bovine milk, that makes this product suitable for infants, elderly or sensitive patients. The main differences in chemical composition between a cow and goat milk rely on fat globules that in goat milk are smaller and in fatty acids that present a smaller chain length, while protein, fat, and lactose concentration are comparable. Milk nutritional properties have demonstrated to be strongly influenced by animal diet, genotype, and welfare, but also by season and production systems. Furthermore, there is a growing interest in the dairy industry in goat milk for its relatively high concentration of prebiotics and a good amount of probiotics, which have recently gained importance for their therapeutic potential. Therefore, goat milk is studied as a promising matrix to develop innovative functional foods. In addition to the economic and nutritional value, goat milk is considered a sustainable product for its small environmental footprint, as they require relatively little water and land, and less medical treatments, compared to cow, these characteristics make its production naturally vocated to organic farming. Organic goat milk production has becoming more and more interesting both for farmers and consumers as it can answer to several concerns like environment protection, animal welfare and economical sustainment of rural populations living in marginal lands. These evidences make goat milk an ancient food with novel properties and advantages to be valorized and exploited.

Keywords**—**Goat milk, nutritional quality, bioactive compounds, sustainable production.

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I. Introduction

GOAT milk is a growing agricultural sector. In the world, goat milk production represents 1.9% of the milk production, where the bovine milk production represents the 83.1% and the sheep milk production is 1.3%. In the last 50 years, the goat milk production has doubled, with a milk production of 15.262.116 tons in 2016, and it is still growing. The goat's population is concentrated in Asia (52.7%) and Africa (25.7%), in arid areas characterized by low income people and food security problems.

The goat milk production in Europe represents the world's highest production with the 16.6%, with only the 4.3% of goats. In Europe, four countries (France, Greece, Italy, and Spain) produce 9.4% of the world goat milk [1], where milk is processed on farm into dairy. In Italy in particular, dairy goat production is based on local breeds raised under extensive or semi-intensive systems. Italian goat population is the largest but shows the lowest yield compared to the other countries, even if the production has grown significantly in the last years from 2010 to 2017 (Fig. 1).

The market of goat milk is becoming very promising for reasons linked to its nutritional quality, potentialities as functional food and production sustainability. These properties, taken all together make goat milk a food able to satisfy the needs of both developed and developing countries.

In developing countries, but also in many marginal regions of the Mediterranean area, the goat production seems to be a good answer to solve problems linked to food security, climate change and desertification. Goats require relatively little water or land, and less medical treatments, compared to cow farming. In fact, these small ruminants are able to convert efficiently poor weedy plants and crop by-products into traditional products of high nutritional quality, showing a great resilience to different climatic and environmental conditions.

These characteristics, together with the use of extensive management systems often not changed in centuries, ensure also high animal welfare standards and an organic-oriented production that are favorably perceived by the developed countries market. In developed countries, goat's milk and its by-products has always been considered a delicacy, but nowadays it is mostly consumed because is an excellent source of high biological value compounds such proteins, essential fatty acids, minerals and vitamins. Recently, goat's milk has gained popularity also among people with intolerance to cow's milk or suffers from digestive disorders [2].

Goat's milk has been studied also as a functional food or as a good matrix to add functional components, such as prebiotics or probiotic bacteria [3].

This paper's aim is to highlight the advantages of goat's milk production in terms of high nutritional qualities, environmental and social sustainability. Recent studies on the factors affecting nutrition quality and on goat's milk as functional food will be also reported.

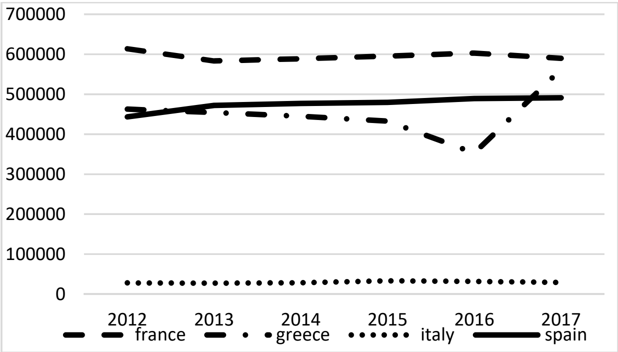

Fig. 1 Goat's milk production (ton), years 2012-2017

II. Nutritional Quality

Goat's milk can provide many nutrients of high biological value both for adults and children. Major nutrients such as proteins, lipids and carbohydrates but also minor components such as minerals, bioactive compounds and vitamins (Table I). Major and minor nutritional components will be examined for profile, concentrations and impact on human health.

TABLE I
COMPARISON OF THE NUTRITIONAL COMPOSITION OF GOAT AND COW MILK [36]

Chemical Composition	Goat	Cow [a]
Protein (g):	3.9	3.3
Casein (g)	2.5	2.7
Carbohydrates (g):	4.7	4.9
Sugars (g):	4.7	4.9
Lactose	4.1	4.8
Energy (kcal):	76	64
Sodium (mg):	40	50
Potassium (mg):	180	150
Iron (mg):	0.1	0.1
Calcium (mg):	141	119
Phosphorous (mg):	106	93
Magnesium (mg):	13	12
Zinc (mg):	0.31	0.38
Copper (mg):	0.03	0.02
Selenium (μg):	1.9	1.6
Vitamin B1 (mg):	0.05	0.04
Vitamin B2 (mg):	0.11	0.18
Vitamin B3 (mg):	0.3	0.1
Vitamin A. (ug):	86	37
Vitamin C (mg):	1	1
Vitamin E (mg)	0	0.07

Data are expressed for 100g of milk.

A. Lipids

Lipids present in goat's milk have different characteristics from other ruminants' milk, even if the average fat content is quite similar. The fat fraction is composed mainly of triacylglycerols (~98% of the total fat), with minor amounts of phospholipids, cholesterol, free fatty acids, and mono- and diacylglycerols [4]. Two main characteristics increase goat's milk digestibility in comparison to cow's milk (Table II). First, the size of fat globules is smaller than those in cow milk. In particular, the fat globules smaller than 5 μm are the 80% in goat milk, while they are the 60% in cow milk. Second, the difference in fatty acids composition, goat's milk contains 15-18% of medium-chain fatty acids, i.e., caproic (C6:0), caprylic (C8:0) and capric (C10:0), while in cow's milk it is under the 9% which are partly responsible for the peculiar flavors of goat dairy products. Another health-promoting component of the lipid fraction of goat's milk is the conjugated linoleic acids (CLA). CLA are 18-carbon fatty acids, that are been linked to a cardiovascular diseases, cancer and arteriosclerosis risks reduction [5].

TABLE II
COMPARISON OF LIPIDS CONTENT OF GOAT AND COW MILK [36]

Chemical Composition	Goat	Cow [a]
Lipids (%)	4.8	3.6
Colesterol (mg)	10	11
Saturated (%):	3.32	2.11
C4:0÷C10:0	0	0
C12:0	0.22	0.11
C14:0	0.49	0.37
C16:0	1.34	0.92
C18:0	0.43	0.39
C20:0	0	0
C22:0	0	0
Monoinsaturated (%):	1.36	1.1
C14:1	0	0.07
C16:1	0.11	0.1
C18:1	1.25	0.93
C20:1	0	0
C22:1	0	0
Polinsaturated (%):	0.16	0.12
C18:2	0.11	0.07
C18:3	0.05	0.05
C20:4	0	0
C20:5	0	0
C22:6	0	0

Data are expressed for 100g of milk.

Sphingolipids, are a class of lipids characterized to have, together with phospholipids, positive activities for human health [6]. The main properties recognized to these molecules are se role of signal during the processes of cell growth and cell differentiation [7] and to be an important structural part of the cell. They have also anticancer, cholesterol-lowering and antibacterial activities. Yao et al. [8] reported how these lipids are significantly higher in goat's milk respect other mammals (i.e. 28% more than human milk).

B. Carbohydrates

Lactose is the major free carbohydrate in the milk of the goat, and it is its major component its concentration is usually lower than that found in cow milk (on average, 4.1% vs.

4.7%), but not at level that can be considered safe for lactose intolerant patients.

Other carbohydrates present are oligosaccharides (OS) glycoproteins and small amounts of inositol. There are also sugars that are not digested by humans but have the important role of feeding the intestinal commensal microbes, acting as prebiotic compounds [5], [9].

OS are compounds based on lactose with an addition of different monosaccharides by enzymatic reactions. OS have gained attention in scientific literature because they demonstrated to promote the growth of the intestinal flora in newborns that prevents diarrhea and has anti-inflammatory effects besides enhance brain growth in children. These properties are especially due to the presence in goat's milk of fucosylated and sialylated OS [5]. The concentration of goat's milk oligosaccharides is higher than those of cow's and sheep's milk [7], even it is lower than human milk (250-300 mg/L vs 12-13 g/l), but structurally goat's milk OS are quite similar to breast milk.

C. Protein

The caseins are classified as κ-, β-, αs1-, αs2-, and γ-caseins and the whey proteins as β lactoglobulin, α-lactalbumin, serum albumin, and immunoglobulins. The casein content in goat's milk represents 74% of total milk proteins, whey proteins amount nearly to 17%, the remaining 9% are non-protein nitrogen [3].

The precursor amino acids are similar in goat and cow milk but there are some proteins that are present only in goat milk such as ansiotensinogen, with effect of reducing blood pressure or protein classified as defense factors [10].

Important dissimilarities in the structures of lactalbumines present in goat milk can avoid important allergic reactions in patients sensitive to bovine milk. Also, caseins show important differences among ruminant species milk, especially the level of αS1-casein. The level of αs1-casein in goat milk ranges from 0 to 7 g/L (89% less than cow milk), providing a less allergenic milk. In fact, αS1-casein is not present in human milk. This variability is associated with polymorphisms within the alpha s1-casein gene, which are very common in goats. Therefore, also the casein micelles are smaller in goat milk than cow milk, this makes it more digestible [11].

D. Minor Nutrients

1. Minerals and Vitamins

The mineral content of goat milk (magnesium, iron, calcium, copper and phosphorous) varies from 0.70 to 0.85%. The minerals present in goat's milk show a higher bioavailability than cow's milk. Goat's milk in a source of high-quality calcium, and it has been studied that its consumption in children can improve growth and skeletal mineralization [12]. Goat's milk differs from cow's milk in its much lower content of B1 (thiamine) but higher in vitamin A (47%) and vitamin B6 (25%). The vitamin A generated from the completely conversion of all carotenes.

2. Minor Bioactive Milk Components

Goat's milk contains a great number of minor bioactive components that exert many positive and fundamental functions in many physiological processes [13]. Polyamines, putrescine (PUT), spermidine (SPD), and spermine (SPM) are bioactive compounds active in cellular growth and differentiation, they also are intracellular messengers. Recently, they have been involved in the control of diabetes, as they show a significant antiglycation effect [14]. Milk is the first source of exogenous polyamines for newborn babies, where they decrease the frequency of food allergies. Goat colostrum and milk content in polyamines is higher than that observed in milk from other mammals, this is particularly true for SPD [7].

III. Goat's Milk as Functional Food

Probiotics are living microorganisms able to live in human gut and produce several health benefits, their nourishment are prebiotics, indigestible substances like inulin and oligosaccharides that promote their growth.

Goat's milk is commonly exploited as a carrier of prebiotic substances and probiotic cultures carrier [15], because for its physical-chemical properties, nutritional composition, low allergenicity and high digestibility, that make it suitable for infants and elderly. The most used prebiotics are inulin and oligofructose [16]. The introduction of a goat's milk enriched with these two prebiotics in the animal model diet changed the gut microbiota with positive effect to health.

As described in the previous section, goats' milk is naturally rich in oligosaccharides. Further studies demonstrated the possibility of produce milk enriched in OS coming from the goat's milk whey resulted after cheese production as to become a functional food useful to preserve gut health [17].

Raw goat's milk has been studied as a source of probiotics [18] and also fermented goat milk with known probiotic bacteria reported many health benefits, such as antioxidative and anti-atherogenic effects from fermented goat's milk using Lactobacillus fermentus ME-3 (LAB) [19]. Other beneficial compounds produced during LAB fermentation process are vitamins, enzymes bioactive peptides, and exopolysaccharides (EPS), that have displayed antimutagenic properties [20]. LAB is able to convert lactose into glucose and galactose by the b-galactosidase, that is therefore important for lactose intolerant [21]. A popular example of fermented goat's milk is Kefir, produced by mesophilic and thermophilic LAB and acetic acid bacteria.

There is also the possibility to have goat's milk rich in symbiotics. Symbiotics are a mix of probiotics and prebiotics, whose action on health is synergistic and therefore called symbiotic. They have the ability to improve on the one hand the survival of probiotic organisms and on the other to promote the formation of a specific substrate for the already resident intestinal bacterial flora [22].

IV. Factors Affecting Nutritional Quality

There are many factors affecting nutritional quality of goat's milk, among the most important, the farming system, feeding, goat breed and genetic characteristics. It the most important aspect seems to be feeding and not farming methods and this seems independent of energy intake. Goats raised on pasture produce milk with a higher fat content, rich in fatty acids and vitamins, phenolics compounds respect goats fed with concentrate forage, due to a diet rich in fiber. In particular, a high percentage of leguminous in the feeding can increase unsaturated fatty acids, CLA and bioactive lipids. Grass feeding also enhances the presence of phenolic compounds with beneficial effects on antioxidant activity [23]. Richness in medium chain fatty acids, peculiar of goat's milk, can be also related to a more efficient utilization of fat by goats respect other ruminants [12].

The presence and type of caseins is strongly influenced by animal genetic, and the selection of goats with null casein alleles has been studied for hypoallergenic milk production or animal with strong alleles for improved dairy products. Genetic polymorphism has evidenced also for fatty acids, this consideration led to studies combining different diets in relation to genetic profile to modulate the milk quality according the consumers' needs [24].

Mediterranean herbs, sage, rosemary, thyme and borage, have been has been seen to improve the quality of goat milk in terms of antioxidant properties. The introduction of 20% of distilled aromatic plant leaves in the diet of goats has been studied. The result was an increase of flavonoids, gallic acid and terpenes in milk, and an increase of polyunsaturated fatty acid content [25].

V.goat's Milk Sustainability

The production, processing and distribution of milk and dairy products, like other foods, impacts the planet. Milk production systems are important and complex sources of greenhouse gases emissions, in particular methane (CH_4), nitrogen oxide (N_2O), and carbon dioxide (CO_2). Globally, the dairy sector accounts for about 4% of all anthropogenic emissions, of which milk production, treatment and transport represent 2.7%. The growth and supply of food involves some environmental effects and efforts are underway in the dairy sector to reduce the intensity of emissions.

Sustainable development aims to exploit natural resources for human needs preserving the natural environment so that these needs can be satisfied in the indefinite future. The concept of sustainable development includes three main categories of action: environmental, economic, and social.

In the past, livestock was deemed guilty of great environmental damages, but nowadays this conclusion has been revised, and only intensive systems, as beef production, are still considered negatively [26].

It is estimated that more than 30% of arable-crops grown are fed to intensively raised livestock. On the contrary, goats are mostly kept in extensive/semiextensive low-input systems with, in most cases, a little environmental impact. They are adapted to raise in woody rangelands and have developed particular anatomic characteristics, efficient metabolism and browsing ability. Goats have also developed a selective feeding behavior in order to prefer forages with high nutritive value. Therefore, they are able to select a balanced diet throughout the year with negligible supplementation.

In many countries with difficult, arid and impervious lands, they represent the only kind of livestock able to maintain poor economies and ensure food security for the poor keepers. In some cases of rangeland deteriorated by cow and sheep overgrazing, goats remain the only alternative, and their introduction happens frequently in degraded territories [27].

Biodiversity is a great value for a sustainable development and for a healthy environment. The employment of a narrow number of goat breed, especially in Europe, has caused a big loss of genetic variability. Local breeds are often more efficient and adapted to the environment, and this is not only important from an economic point of view (high milk yield, low case of diseases, etc.), but also for the impact on the local plant biodiversity [28]. For example, the presence of white clover is increased with the presence of goats compared to sheep, this reveals to be significant to establish a rotational management of livestock in determined sensitive areas [29].

Also, animal biodiversity conservation has great advantages from the browser behavior of goats [30].

Goats can help to restore the cycling of plant nutrients sequestered by woody species with a good effect on carbon sequestration and tree production maintaining the carbon footprint lower than other ruminants. Besides, they facilitate the return of nutrients to soil with manure and urine [31]. These small ruminants demonstrated to be a good biological control agent in the control of fire, as they prevent the accumulation of wood, with a great contribution to biodiversity conservation, global warming and desertification [32].

A reduction of 45% of biomass has been observed in many areas as result of goat grazing. This approach is used in countries with fire risk such as Spain, Corsica, California, Tanzania [29], [32], [33]. In these areas, a substantial reduction in costs and environmental pollution, compared to the traditional chemical and mechanical methods used for fire prevention is observed.

Crop-by products have been proposed as a good diet supplementation for goats, with beneficial effects on milk quality and on environment to avoid overgrazing especially during the dry season [34]. Climate change, desertification and water scarcity are problems that should be faced worldwide. Goats are able to afford feed shortage, droughts better than other ruminants; this has led to the replacement of cattle by dromedaries and of sheep by goats in the Sahel after the droughts of the 1980s. This resilience is due to because goat need a little amount of water, for example to produce 2$ of income from grain 500 L of water are needed, while only 4 L to produce the same income from goat milk [27].

The emission of methane from livestock is a great contributor to global warming, and it mostly derives from the storage of manure in anaerobic conditions, but this is related to beef production not to goats that for African goats is estimated to produce only the 0.6% of all methane emissions in the world.

Organic milk has gaining great popularity, because it is perceived has healthier, free of pollutants and respondent a more ethical principles regarding animal welfare and respect for environmental resources traditional practices. For its characteristics, goat milk systems can fit without many efforts organic production requirements. The exploitation of marginal land for the production of organic goat milk could be a promising way to enhance poor economy in depressed areas [35]. In this prospective, European Union has financed the project FLOCK-REPROD from 2009 to 2013. In accordance with EC regulation (96/22/EC) which restricts the use of exogenous hormones in animal reproduction, the project suggests innovative solutions to ensure the supply of hormone-free goat's milk all year round.

VI. Conclusion

Researches in goat’s milk nutritional properties have demonstrated the important role that this food can play in human nutrition. Its digestibility and low allergenic power, together with high content of vitamins, minerals and bioactive compounds, make this food particularly suitable for children and sensitive people. The goat milk production can satisfy different requirements:

- Educated people from developed country in search of an environmentally friendly production, respectful of animal welfare and with functional properties;
- Breeder from developing countries or living in disadvantaged areas, looking for a low-cost animal, that need less feed and water, no housing, resilient to drought and able to survive to extreme environmental conditions

These considerations could driver new investments and governments aids in the goat milk, both for promoting and sustain local farmers, both to finance new research for products quality enhancement.

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