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Goat Milk: Compositional, Technological, Nutritional and Therapeutic Aspects: A Review

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ABSTRACT

Since the 1980s, a growing interest in goat milk was noticed due to the nutritional values and health benefits of this milk, which resulted in increasing goat populations and milk production worldwide. This comprehensive review elaborates on goat milk composition compared to other types of milk. It is also an overview of goat milk production, properties, nourishment value, applications in dairy products and potential health benefits. Goat milk composition and its characteristics are slightly different from other types of milk and can be utilized to manufacture many dairy products. Fresh goat milk and goat milk products (*e.g.,* yogurt and kefir) were found to provide various potential health benefits, such as anti-inflammatory, preventing cardiovascular disease, anti-diabetic and antihypertensive, strengthening bones, boosting immunity and improving metabolism.

Key words: Goat cheese, Goat milk, Goat population, Milk composition, Milk production, Therapeutic properties.

Milk and meat are the two main reasons for raising goats. The Food and Agriculture Organization (FAO) reported that the number of goats has skyrocketed from 350 million to over 1 billion during the last 60 years (Fig 1) where China has the largest herd worldwide (FAO 2018).

The majority of goats occupy large pastoral lands in Africa and Asia (Fig 2). Goat milk is mainly utilized for human nourishment in many places in Asia, Africa, Mediterranean countries and Middle Eastern countries. All these regions have something in common in which their economies are rapidly developing and have an exploding population to feed (Bhardwaj *et al*. 2018). Thus, animal protein has paramount importance in such regions. For the same reasons, goat milk is utilized nowadays in South and North America, Europe and Oceania. Research has shown that all the essential nutrients found in cow milk exist in goat milk, such as protein, fat, mineral and lactose (Loewenstein *et al*. 1980; Prajapati *et al*. 2017). Approximately 49% of the world's goat milk production is produced in India, Sudan, Bangladesh and Pakistan (Dhanalakshmi and Gawdaman 2013; FAO 2018). Goat milk can be consumed fresh, or it is utilized to manufacture one of the common traditional dairy products, such as Panner cheese in India (Agnihotri and Pal 1996), goat cheese and butter in Bangladesh (Haenlein 2004) and Gibna Beida cheese in Sudan (Abd El-Salam and Alichanidis 2004; Sepe and Argüello 2019). The surplus amount from goat milk is dried and exported to other countries with a deficiency in goat milk production.

Fresh goat milk and goat yogurt have been utilized to treat several diseases (Lara-Villoslada *et al*. 2006; Assis *et al*. 2016). Goat milk and its products have promising health benefits besides their nutritional values (Maesela *et al*. 2019). Recently, research on goat milk and its products found promising results in medical applications, such as anti-carcinogenic (Lima *et al*. 2018), antidiabetic (Nurliyani *et al*. 2015) and antihypertensive (Ibrahim *et al*. 2017). Furthermore, goat milk enhanced the metabolism (López Aliaga *et al*. 2000; Lopez-Aliaga *et al*. 2003) and the immunity (Castro *et al*. 2005; Rodríguez *et al*. 2009).

Goat milk did not attract many researchers and consumers at the beginning of the 1970s (Clark and Mora García 2017). Previous papers reviewed the composition and application of goat milk in the manufacture of different dairy products (Loewenstein *et al*. 1980; García *et al*. 2014; Skeie 2014; Clark and Mora García 2017). Therefore, this review aims to elaborate the present data and information on goat milk production and composition, goat milk characteristics, nutritional value, applications in dairy products and its contribution to the health benefits.

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Historical overview

Many studies were focused on goat milk due to its unique characteristics and significant health benefits of the milk. A historical overview of selected milestones for goat milk is illustrated in Table 1. Goat milk was consumed since the beginning of domestication and was proved that it had been used in making cheese since 3200 BP when discovered in an Egyptian tomb (Greco *et al*. 2018). Dalebrook published the first goat milk study in 1902 that concentrated on the health benefits of goat milk when it was fed up to infants (Dalebrook 1902). A few years later, it was discovered that goat milk could rarely form a cream layer as compared to cow milk (Edmunds 1914). In 1921, this issue was solved by Schultz and Chandler when they recognized that the diameter of 91% of goat milk fat globules was <4 µm (Schultz and Chandler 1921). Sooner after, it was reported that the globulin in goat milk colostrum could transfer the immune bodies from mother to young goats (Bergman and Turner 1937).

The diet effect in goats was studied in 1951 and was found that goat colostrum and goat milk had a higher amount of vitamin B_{12} during the first week postpartum (Harper *et al*. 1951). A couple of years later, Elvehjem found that feeding rats with goat milk led to slow growth of rats as compared to cow milk (Elvehjem 1953). In 1968, it was recognized that goat milk was deficient in folic acid, vitamins B_{12} and B_6 when it was fed to infants (Ford and Scott 1968; Parkash and Jenness 1968). Subsequently, goat milk attracted many people to study its health benefits, nutritional values and functional characteristics (Jenness 1980). It has been reported that goat milk assisted to lessen some food allergies (Haenlein 2001). Goat milk has unique characteristics and a wide range of applications; as a result, many studies are nowadays investigating different aspects of goat milk.

Goat milk production

In 1961, the world production of goat milk was about 7.0 million metric tons (MMT) (Fig 1), representing 2.0% of 344.2 MMT overall milk production produced from cow, buffalo, goat, sheep and camel. Goat milk production is not comparable to cow milk, which is about 2.2% goat milk compared to 81.0% cow milk of the world milk production (FAO 2018). In 2018, goat milk production elevated to approximately 18.7 MMT representing 2.2% of the overall milk production (843.0 MMT) in the world (FAO 2018). The trend of goat population in the world is shown in Fig 1 and Fig 2. The goat populations increased significantly from approximately 350 million to more than 1 billion heads during the last 60 years, which is about a 200 % increase compared to a 21.6 % increase in sheep populations during the same period (FAO 2018). The interest in goat milk is not only because of accepting goat milk as a food source but also due to the medical, nutritional, biological and immunological applications of goat milk (Jandal 1996; Bevilacqua *et al*. 2001; Park and Haenlein 2006). As a result, goat milk is nowadays one of the new trends in functional foods in many developed countries in Asia, Africa, Mediterranean countries and Middle Eastern countries, as well as in South and North America, Europe and Oceania (Fig 2).

The growth in goat milk production is also reflected in spreading the knowledge of goat milk around the world, which led to increasing the utilization of goat milk and its products for nutritional or medical purposes. Moreover, it is an essential food to protect poor people and farmers from malnutrition. Additionally, goat milk is suitable for people who are suffering from gastrointestinal manifestations (Carvalho *et al*. 2012; Alférez *et al*. 2015). Besides those advantages, the cost of raising goats is less because they require less space as compared to cows. The average daily milk production of goats ranges from 2 and 5.5 kg during the lactation period (Min *et al*. 2005) and this depends on different factors, such as breed, feeding, lactation stage and environment. Morand-Fehr *et al*. (1991) reported that milk production decreased from 2.1 to 1.7 kg/day when the goats have fasted for 24 hours. This study also showed that when the level of intake (roughage: hay) changed from 593: 1222 g/day to 1389: 669 g/day the milk production increased from

Table 1: Selected scientific and commercial milestones in goat milk production and applications.

Year	Milestone	Reference
1902	First published work on goat milk. It concentrated on studying the risks and benefits of feeding infants on goat milk.	(Dalebrook 1902)
1914	First discovered goat milk rarely can form a layer of cream on the surface.	(Edmunds 1914)
1921	First found 91% of goat milk fat globules were <4 µm in diameter.	(Schultz and Chandler 1921)
1937	First found a correlation between globulins in goat milk and immune bodies.	(Bergman and Turner 1937)
1951	Studied the diet effect in goats and found a higher amount of vitamin B_{12} colostrum and milk during the first week of postpartum.	(Harper *et al*. 1951)
1953	First found the growth of rats is slow when they are fed up with goat milk as compared to cow milk.	(Elvehjem 1953)
1968	Found that goat milk was poor in folic acid, vitamins B_{12} and B_6 when it was fed up to infants.	(Ford and Scott 1968; Parkash and Jenness1968)
1980	Goat milk products attracted a huge interest due to their health benefits and nutritional values.	(Jenness 1980)
2001	The first evidence of lessening allergies by consuming goat milk.	(Haenlein 2001)

2.69 to 3.21 kg/day, respectively. Consequently, the factors that affect goat milk production can also result in substantial variations in the composition of the milk.

Goat milk composition

The mean values of goat milk composition are 3.3% protein, 4.0% fat, 4.3% lactose, 0.8% ash and 12.6% total solids. The milk produced from different animals has the same essential components (Fig 3). Both cow and goat milk are similar and contain a high amount of protein and minerals, while lactose is less relative to human milk (Soliman 2005; El-Hatmi 2015; Yadav *et al*. 2016; Lima *et al*. 2018).

Goat milk composition was found to be less stable relative to cow milk. The composition of goat milk is markedly varied during the lactation stage (Fekadu *et al*. 2005) due to the abovementioned factors that affected goat milk production (Park 1990). Morand-Fehr *et al*. (1991) found that the fat (3.1%) and protein (2.7%) content elevated to 3.6 and 3.9%, respectively, when the goats have fasted for 24 hours. This study also reported that changing the level of intake (roughage: hay) from 593: 1222 g/day to 1389: 669 g/day led to a slight decrease in the fat content from 2.68 to 2.59%, respectively. The changes in milk composition could result in variations in the quality and consistency of the products manufactured from goat milk.

Fig 4 illustrates the trend of goat milk composition during 10 months of lactation. The highest values for solids, protein and fat were obtained at the beginning of the lactation stage or after parturition (approximately 23.2, 17.4, 7.3 and 5.9%, respectively) and then these values become stable after 1 month (Masmas *et al*. 2011; Kljajevic *et al*. 2018). However, the average lactose content was low (3.0%) after parturition and then soared to approximately 4.7% after one month of lactation to be stable during the rest of the season (Fig 4). Chen *et al*. (2014) reported a similar trend in cow milk composition. Approximately 70% of the protein content in goat milk is casein (insoluble in water) and 25% is whey protein (soluble in water), while 5% is fat-soluble milk fat globule membrane protein (Chen *et al*. 2019; Li *et al*. 2020). It has been reported that goat milk has lower αs_1-casein and lactose as compared to cow milk which allows β-LG (Lact oglobulin) and lactose to be digested easily with less allergenic (Bevilacqua *et al*. 2001; Lara-Villoslada *et al*. 2004; Chen *et al*. 2018).

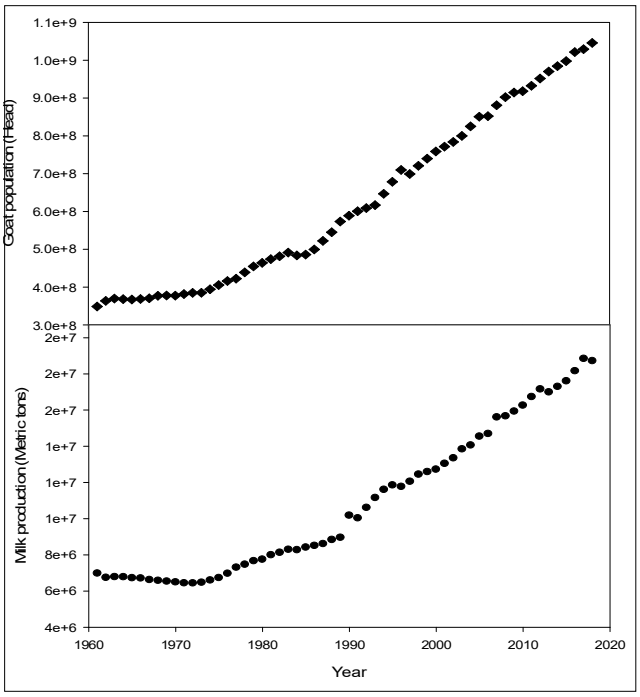

Fig 1: World goat populations (♦) and milk production (●) during the last 60 years. source: FAO (1961-2018).

Goat milk properties

Goat milk is a white opaque liquid because goats have high efficiency in converting beta-carotene pigment (responsible for the yellowish color) to colorless vitamin A. The components in goat milk (such as protein, lipid, minerals and vitamins) have unique characteristics and a significant role in human nutrition relative to other milk (Park and Haenlein 2007). The physio-chemical merits of goat milk have been deliberated in different research (Haenlein and

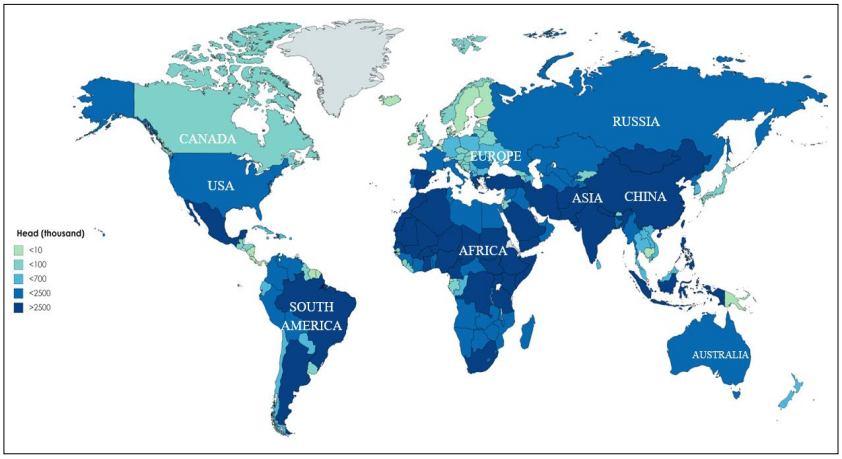

Fig 2: Distribution of goat populations in different regions around the world during the last 60 years. source: FAO (1961-2018).

Wendorff 2006; Park *et al*. 2007). They informed that goat milk has an elevated viscosity (2.12 Cp) and acidity (0.23%) as compared to cow milk (2.0 Cp and 0.18% viscosity and acidity, respectively). However, the density (1.029-1.039), refractive index (1.45), surface tension (52.0 dynes/cm), conductivity (0.0043-0.0139 µs/cm) and freezing point (0.54-0.57 below 0°C) of goat milk are in the range of cow milk values (Haenlein and Wendorff 2006; Park *et al*. 2007).

Furthermore, there are differences between the goat and cow milk in the diameter of fat globules; thus, the diameter of fat globules is around 2.7 µm in goat milk and 3.5 µm in cow milk (Attaie and Richter 2000). As a result, homogenization is not required in goat milk, which means processing costs can be lower in goat milk as compared to cow milk. Additionally, the small sizes of fat globules in goat milk result in a smooth texture in dairy products (Pal *et al*. 2017).

Goat milk dairy products

Goat milk is widely utilized in manufacturing many dairy products due to its high digestible, hypoallergenic and nutritional characteristics (Lou *et al*. 2018; Chen *et al*. 2019). Goat milk is used to make cheese, yogurt, butter, ice cream and infant formula in some countries (Prosser *et al*. 2008). The composition of different products made from goat milk is shown in Fig 5.

Cheese

Goat cheese is the most valuable product made from goat milk because it has more shelf-life. It was first originated in Egypt by the Ancient Egyptians and was discovered recently in a 3,200-year-old BP tomb (Greco *et al*. 2018). The U.S. Department of Agriculture has described more than 400 types of goat cheese named under different names and

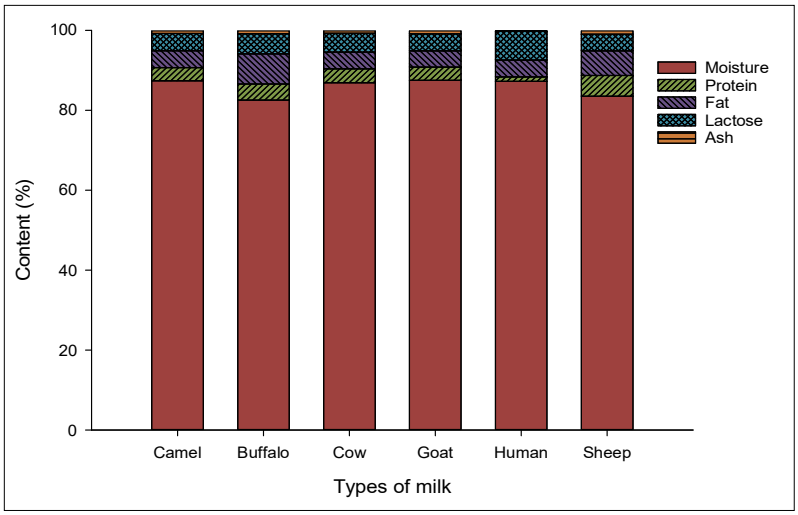

Fig 3: Mean composition of goat, cow, camel, buffalo and human milk. Adopted from (Soliman 2005; Lima *et al*. 2018).

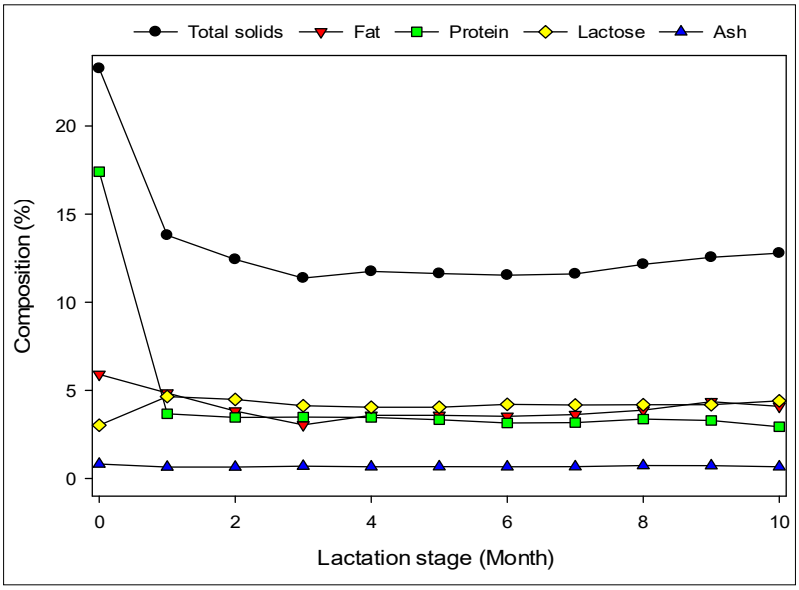

Fig 4: Mean composition of goat milk during 10 months of lactation. 0 month= composition of colostrums goat milk through the first three days after parturition. Adopted from (Masmas *et al*. 2011; Kljajevic *et al*. 2018).

made from goat milk only or a mix of goat milk with cow, ewe, or buffalo milk (Park 1990, 2010). The total production of goat cheese in the world was more than 500,000 tons in 2014 (Fig 6) (FAO 2018). The goat milk is utilized to manufacture many types of soft cheese (namely, Gibna Beida in Sudan, Karish and Domiati cheeses in Egypt, Feta cheese in Egypt and Greece and Camembert cheeses in France) and hard cheeses (including Chevrotin cheese in France, Ras cheese in Egypt, Kefalotili cheese in Greece and Manchego cheese in Spain) made from raw or pasteurized milk especially in the Mediterranean countries (Park 2001; Mehaia 2002; Ismail and El-Demerdash 2003). The developed countries are commonly producing many kinds of traditional goat cheese.

As mentioned previously, goat milk composition over the season can change due to many factors, thus affecting the consistency and quality of its dairy products. This variation in goat milk composition on the yield and sensory quality of semi-hard cheese and hard cheese was examined in a research study. The consistency of flavor, body and texture and total sensory scores of those cheeses were maintained during 8, 16 and 24 weeks of aging (Fekadu *et al*. 2005). As a result, goat milk can be successfully utilized in making cheese with not much variability in the characteristics of the cheese.

Yogurt

Yogurt is also considered one of the main dairy products in the markets and is commonly made from cow milk. The yogurt production has significantly elevated from 1.6 billion kg in 2008 to over 2 billion kg in 2018 in the US (Milani and Wendorff 2011; Chandan *et al*. 2017; Tsevdos 2019). Yogurt is manufactured by adding lactic acid bacteria to skim, low-fat, or whole goat milk for fermentation. Loewenstein *et al*. (1980) reported that goat yogurt has low firmness or is softer and less viscous as compared to the yogurt made from cow milk due to the low content of αs_1-casein and small fat globules in goat milk (Alichanidis and Polychroniadou 1996). In addition, goat milk yogurt often does not provide the typical flavor of cow milk yogurt during the lactation period. It has been found that the acetaldehyde in yogurt made from goat milk obtained after 2-3 weeks and 8 months of parturition was lower (6 and 9 ppm respectively) as compared to 18 ppm in cow milk. However, this study found that diacetyl and acetoin were similar in yogurt made from goat and cow milk (Rysstad and Abrahamsen 1987).

Beverages

There are only a few research papers on the manufacture of beverages from goat milk (Pandya and Ghodke 2007; Ribeiro and Ribeiro 2010; Lou *et al*. 2018). Goat milk can be utilized to produce low-fat milk by standardizing the fat and solids to 2% and 12.5%, respectively. The composition of fluid milk is shown in Fig 5. Goat milk is susceptible to off-flavor which could lead to variations in the flavor of processed goat milk (James 1976). However, sterilization and drying can be applied to goat milk to produce fluid milk for consumption during the wintertime with not much variation in the composition and flavor of this milk (Pandya and Ghodke 2007).

Other products

There are numerous applications for goat milk to be utilized in manufacturing different dairy products. Goat milk can be utilized to manufacture whey protein concentrate (Casper *et al*. 1999), powdered goat milk (whole milk, skim milk and infant formula), fermented milk such as Kefir (Nair and Prajapati 2003; Farnworth 2006), evaporated goat milk (Pandya and Ghodke 2007; Park 2010), fat-rich products (Sağdıç *et al*. 2004) and frozen products (Loewenstein *et al*. 1980).

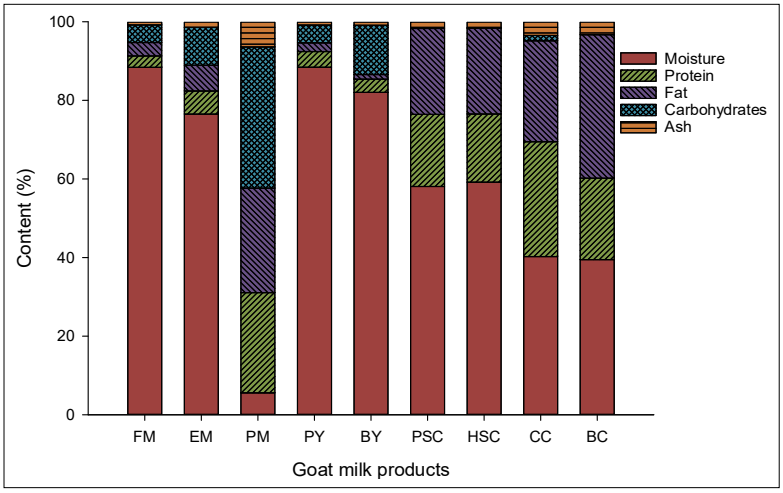

Fig 5: Mean composition (%) of commercial U.S. goat milk products. adopted from (park 2010). FM= Fluid milk; EM= Evaporated milk; PM= Powdered milk; PY= Plain yogurt, BY= Blueberry yogurt; PSC= Plain soft cheese; HSC= Herb soft cheese; CC= Cheddar cheese; BC= Blue cheese.

Therapeutic benefits of goat milk

The consumption of goat milk has elevated recently because it is easily digested and this, in turn, makes goat milk and its products attractive and recommended for children, adults and elderly people (Lima *et al*. 2018). As well, goat milk has potential health benefits, such as anti-inflammatory, anti-hypertensive, anti-diabetic, boosting immunity system and strengthening bones (Silanikove *et al*. 2010; Lima *et al*. 2018).

Anti-inflammatory properties

Goat milk is a good alternative to infants with intolerance to cow milk because it has lower lactose content and higher quantities of short chains, medium chains, mono and polyunsaturated fatty acids and goat milk is more digestible relative to cow milk (Jirillo and Magrone 2014). Goat milk and its products have unique characteristics against intestinal inflammation. Some investigations have studied the anti-inflammatory and anti-allergic properties of goat milk (Lara-Villoslada *et al*. 2006; Jirillo and Magrone 2014; Assis *et al*. 2016). Jirillo and Magrone (2014) reported that goat milk is a suitable dietary supplement for people with inflammatory and allergic disorders. Another study reported that goat milk and goat yogurt can be effective at lessening or preventing inflammatory bowel diseases (Assis *et al*. 2016). Lara-Villoslada *et al*. (2006) found that oligosaccharides isolated from goat milk reduce intestinal inflammation in rats and provide more favorable intestinal microbiota. These results have shown that goat milk and its products have promising applications to relieve inflammatory diseases.

Cardiovascular disease

Goat milk or its products might help to treat or minimize different cardiovascular diseases. Goat milk fat is easily digested due to its higher content of short-chain fatty acids which is more beneficial (Chilliard and Ferlay 2004). It has been reported that the consumption of goat milk led to a plummet in the plasma cholesterol concentration and plasma triglyceride concentration r (López-Aliaga *et al*. 2005). This could lead to balancing the cholesterol and balancing the essential fatty acids in the human body, so it could prevent atherosclerosis, stroke, heart attack and other coronary disorders (Chilliard and Ferlay 2004).

Goat milk is also a good source of potassium (Kapadiya *et al*. 2016) which could reduce blood pressure because potassium acts as a vasodilator that relieves blood vessels and mitigates tension in the cardiovascular system. Additionally, the high calcium content in goat milk has a positive effect on colon cancer, blood clotting and blood pressure (Kapadiya *et al*. 2016). Moreover, the high magnesium content (20.0 mg/100 mL in goat milk) is favorable to the heart, which is serving to keep a regular heartbeat, prohibiting the formation of blood clots and raising good cholesterol levels (Kapadiya *et al*. 2016).

Antidiabetic and anti-hypertensive

Goat milk or its products have promising applications as anti-diabetic and antihypertensive. The effect of kefir made from goat milk has been studied to determine the improvement of pancreatic β-cells in diabetic rats (Nurliyani *et al*. 2015). Kefir was made from a blend of goat milk and soy milk in that study. It was reported that a mixture of kefir and soy milk can be utilized as anti-diabetic by reducing plasma glucose, elevating glutathione peroxidase activity and enhancing pancreatic β-cells (Nurliyani *et al*. 2015).

Ibrahim *et al*. (2017) reported that goat milk whey and casein could inhibit the angiotensin-converting enzyme that has a significant role in blood pressure regulation by producing the vasoconstrictor angiotensin II. This study concluded that goat milk could act as antihypertensive bioactive peptides and inhibition of associated disorders.

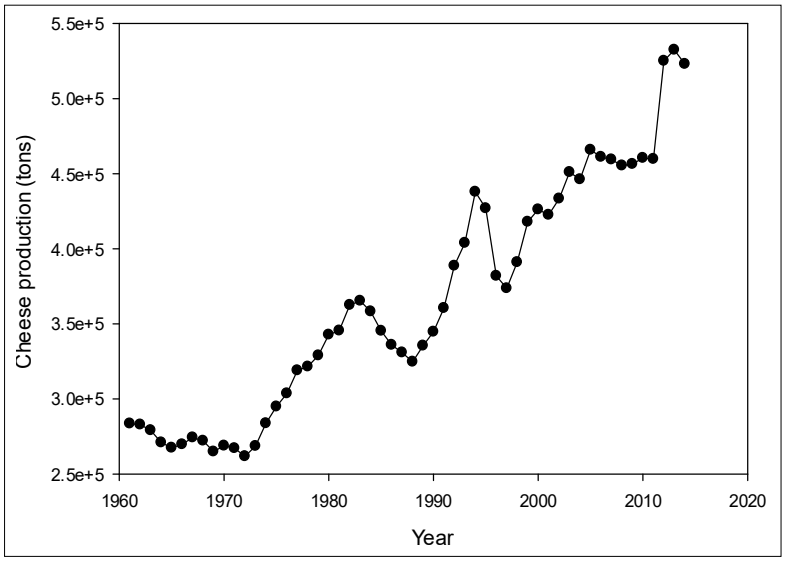

Fig 6: World goat cheese production (tons) during the last 50 years. FAO (1961-2014).

Strengthen bones

Goat milk and its products are good sources of calcium. The calcium content in goat milk is 129.1 mg/100 mL (Kapadiya *et al*. 2016). Calcium is well-known for its role in maintaining the strength and density of bones as referred to as bone mineralization that could prevent osteoporosis. Furthermore, it has been informed that αs_2-casein of goat milk and goat yogurt repaired the collagen structure in the femur trabecular bone (Fatchiyah *et al*. 2015) that provides strength and structure for the bones.

Nutrient uptake and metabolism efficiency

Metabolism efficiency could be positively affected by goat milk and its products. The digestion and nutrient efficiency of some goat milk components have been studied on rats (Alférez *et al*. 2001; Lopez-Aliaga *et al*. 2003). The digestion of goat milk fat is high relative to cow milk due to its higher content of medium-chain triglycerides (Alférez *et al*. 2001). The nutritive application of protein and magnesium in goat milk has been studied in rats (Lopez-Aliaga *et al*. 2003). The consumption of goat milk resulted in higher nutritive utilization of goat protein. Furthermore, the digestibility of magnesium in rats was high (Lopez-Aliaga *et al*. 2003). Moreover, the effect of goat milk on the digestion of calcium and iron was investigated (López Aliaga *et al*. 2000). This study inferred that goat milk could elevate the uptake of calcium and iron in our digestive tract. This could have a positive impact on anemia and other deficiencies in individuals. As a result, goat milk could be able to provide more nutrients as it passes through our system and result in less stress effect on our digestive system. Alferez *et al*. (2001) suggested that goat milk should be included in the diet to help people who have malabsorption disorders.

Boosts immunity

It has been reported that the immunoglobulin of goat milk colostrums produced after parturition has a significant role in passive immune transfer to newborn goat kids (Castro *et al*. 2005; Rodríguez *et al*. 2009). Consequently, goat milk colostrum could be recommended for individuals who suffer low immunity to empower their immunology system. Goat milk has 40% more selenium than cow milk. Only human milk has more significant selenium levels which exceed 60% compared to cow milk (Debski *et al*. 1987). It has been found that there is a correlation between vitamin E and selenium. Thus, these two components can positively enhance the immune system (Kubena and Mcmurray 1996; Seyedrezazadeh *et al*. 2008). As a result, human and goat milk have promising applications to improve the immune system because of their high selenium content.

CONCLUSION

This review discussed goat milk composition, production, properties, nourishment value, its applications in dairy products and potential health benefits. The production of goat milk is elevating nowadays due to the nutritional and health benefits of this milk. Numerous factors affect the variations in goat milk production and composition, such as breed, feeding, lactation stage and environment. Different dairy products were manufactured successfully from goat milk, including cheese and yogurt. Moreover, fresh goat milk and fermented goat milk have potential health benefits because of the bioactive substances in these products. Further work is needed to produce dairy products from goat milk during the lactation stage and investigate the consistency in flavor and characteristics of these products. Future work is required to verify the health benefits of goat milk.

Conflict of interest: None.

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