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Compositional and therapeutic signatures of goat milk: A review

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Abstract
With the paradigm hike in the demand for health-promoting foods, the goat's milk has been reevaluated for its potential human health impact. Goats are one of the major contributors to milk and meat products in India. Albeit major nutritional composition of goat milk resembles cow milk, the goat milk has its unique chemical, nutritional, and therapeutic characteristics. The uniqueness of goat milk lies with the presence of typical short and medium-chain fatty acids, fat globules of smaller size, and softer curd formation that enhance its digestibility with relative lipid metabolism. Caprin milk is a mixture of several bio-augmented compounds that are found to have prophylactic and therapeutic actions against an array of lifestyle diseases, and hence it is considered as a nutritionally sound therapeutic candidate.

Keywords: Goat milk, composition, nutrition, therapeutics

1. Introduction

Goat (*Capra aegagrus hircus*) is a poor man's animal and is the first animal to be domesticated. Their extensive adaptability to adverse climatic or geographical conditions with low cost of maintenance has made them a pliable species of livestock for the marginal and landless farmers. Hitherto, there have been approximately 500 breeds of goats reported globally, wherein only a half are generally domesticated for their milk purposes. Currently, the world goat population is approximately more than 1 billion with the analogous milk production of 18,656,727 tonnes annually (Morales *et al*., 2019) [35]. According to the Food and Agriculture Organization (FAO, 2018) [18], goat milk is the third most-produced varieties of milk followed by cow and buffalo milk. India is the topmost producer of goat's milk in Asia, which is followed by Bangladesh and Pakistan. The goat's milk production has increased more than twofold in the last decade and the market trends suggested that by 2030 will increase by another 53% (Pulina *et al*., 2018) [45].

The growing consumer interest in goat's milk and milk products has been related to the enriched nutritional benefits offered by these products (Clark and García, 2017) [13]. Although mother's milk is nature's best milk that needs to be fed to infants to meet the nutritional requirements, the various factors like time constraints, health conditions, and urbanization led to the termination of breastfeeding. Hence, goat milk has been recommended as an alternative source of milk for infants due to its compositional similarities with human milk and with augmented nutraceutical properties (Kumar *et al*., 2016) [28]. Although there is a similar composition to cow's milk regarding protein, fat, and lactose concentration, the structural differences in the proteins and fats significantly affect the digestibility and nutritional value of goat milk. Moreover, factors like amino acid composition, protein secondary structures, and the chemical properties of goat's milk greatly lowered the allergenic potential as compared to cow's milk thereto (Clark & García, 2017) [13]. Therefore, goat milk can be used in the manufacturing of a wide range of products and can also be used as a carrier for functional components such as prebiotic substances or probiotic bacteria. The developed countries like the United States, the goat's milk is generally consumed by people with intolerance to cow's milk or those who suffer from digestive disorders like ulcers and colitis (Pulina *et al*., 2018) [45].

2. Composition of goat milk

The compositional diversity of goat milk in comparison with the milk of other species has been presented in Table 1. The large compositional variations are common among the milk of different species due to the influence of various factors like individuality, diet, breed, parity, season, feeding regime, management practices, environmental conditions, locality, stage of lactation, and health status of the udder. The energy values of milk of different species have depicted in Table 2.

Table 1: Physicochemical composition of goat milk in comparison with the milk of other species (Sabahelkhier *et al*., 2012) [47] (Posati and Orr, 1976) (El-Hatmi *et al*., 2015) [15]

Components	Goat	Cow	Sheep	Human	Camel
% Moisture	88	87.23	80.7	87.7	88.35
% Total Solids	12	12.8	19.3	12.3	11.7
% Protein	3.3	3.4	6.35	1.2	2.95
% Lactose	4.4	4.8	5.0	6.9	4.3
% Fat	3.9	3.75	6.9	4.0	3.6
% Ash	0.7	0.71	0.85	0.2	0.75
Titratable Acidity (% LA)	0.14	0.12	0.18	-	0.15
pH (at 20 °C)	6.470	6.58	-	7.150	6.460
Density	1.031	1.029	-	1.032	1.0300
Viscosity (cP)	3.45	3.45	-	3.2	3.6

Table 2: Energy values of milk of different species

Species	Energy value/Kg of milk	Reference
Sheep	5932 kJ	Park *et al*., 2007 [41]
Cow	3169 to 3730 kJ	Barłowska, 2007
Buffalo	3450 kJ	Kanwal *et al*., 2004
Camel	3283 kJ	Shamsia, 2009
Goat	3018 kJ	Park *et al*., 2007 [41]
Donkey	1842 to 2051 kJ	Guo *et al*., 2007
Horse	2080 to 2453 kJ	Oftedal *et al*., 1983
Human	2407 kJ	Shamsia, 2009

2.1 Lipid

The fat is one of the vital components of goat's milk with respect to its energy value, nutritional, physical, and sensory characteristics. The lipid profile of goat milk has been shown in Table 3. The fat is present in the form of globules that do not aggregate naturally upon cooling due to the factor that it lacks agglutinin factor (Amigo & Fontecha, 2011) [5]. Goat milk has a higher number of smaller sized fat globules as compared to cow milk; the average fat globule diameter reported to vary approximately from 3.0 µm against 4.0 µm respectively (Gantner *et al*., 2015; Balthazar *et al*.,2017) [9]. Perhaps, these smaller sized fat globules provide a better dispersion and a more homogeneous mixture of fat in the milk. The lipid fraction is composed mainly of triacylglycerols (~98% of the total fat), with minor amounts of phospholipids, cholesterol, free fatty acids, and mono- and diacylglycerols (Taylor &MacGibbon, 2011). Moreover, goat milk fat has reported having significantly higher amounts of short- and medium-chain-length fatty acids (C4:0-C14:0) in comparison to cow and human milk. Nevertheless, the capric, caprylic and caproic fatty acids constitute 15–18% of all fatty acids present in goat's milk, whereas, the same fatty acids represent only 5–9% in cow's milk (Clark & Garcia, 2017) [13]. In fact, the existence of higher amounts of short-chain fatty acids has pivoted towards the differences in the polymerization of acetate produced by the rumen bacteria in the goat'rumen, and this putative composition is associated with the characteristic odor and flavor of goat's milk (Amigo &Fontecha, 2011) [5]. Besides, goat milk is also rich in conjugated linoleic, monounsaturated, and polyunsaturated fatty acids (ω-6 and ω-3 fatty acids, EPA and DHA, and medium-chain triglycerides) that are beneficial for human health and physiology (Morales *et al*., 2019) [35]

Table 3: Fatty acid profile of goat and cow milk (Markiewicz-Keszycka *et al*., 2013) [32]

Fatty acids (g/100g)	Goat	Cow
C4:0; butyric acid	2.03	2.87
C6:0; caproic acid	2.78	2.01
C8:0; caprylic acid	2.92	1.39
C10:0; capric acid	9.59	3.03
C12:0; lauric acid	4.52	3.64
C14:0; myristic acid	9.83	10.92
C16:0; palmitic acid	24.64	28.7
C18:0; stearic acid	8.87	11.23
C18:1 cis-9; oleic acid	18.65	22.46
C18:2 cis-9, cis-12;linoleic acid	2.25	2.57
C18:2cis-9,trans-11conjuated linoleic acid	0.45	0.57
C18:3 cis-9, cis-12, cis-15; α-linolenic acid	0.77	0.5
Total n-6	1.78	2.83
Total n-3	0.44	0.56
Saturated fatty acid	68.79	68.72
Monounsaturated fatty acid	24.48	27.40
Polyunsaturated fatty acid	3.70	4.05
n-6/n-3	5.00	6.01
Total fat (g/100g)	4.27	3.76

2.2 Protein

The casein is the major protein fraction that makes up 74% of total milk proteins, on the other hand, whey proteins contribute to nearly 17% and the proportion of non-protein nitrogen (NPN) compounds is 9% (Al-Saadi *et al*., 2014) [4]. The amount of small-sized casein micelles is relatively higher in goat's milk than cow's milk that explains the better digestibility of goat's milk (Haenlein, 2004) [21]. Amongst casein fractions, κ, β, αS1, αS2, and γ-caseins were elucidated, whereas, β-lactoglobulin, α-lactalbumin, serum albumin, and immunoglobulins have been classified under whey proteins. The β-casein is the principal component of goat milk casein, in contrast, α-S1 is the major component of cow milk casein. Level of α-S2 casein is relatively higher in goat milk but a total of α-S1 and α-S2 casein fractions together are lower than α-S1 fraction alone of cow milk. The protein makeup of goat milk in comparison with cow milk has been presented in Table 4. The differences between the proteins of different species greatly depend on genetic polymorphisms (Raynal-Ljutovac *et al*., 2008).

Table 4: Protein profile of goat milk in comparison with cow milk (Amigo and Fontecha, 2011) [5]

Protein	Concentration %	
	Goat milk	Cow milk
Total casein	2.33-4.63	2.4-2.8
αS1 Casien	0.0-28.0	50.0-53.6
αS2 Casien	10.0-25.0	12.5-14.3
β-Casien	06-64.0	37.539.3
κ-Casein	15.0-29.0	8.3-14.3
Whey proteins	0.37-0.70	0.5-0.7
β-Lactoglobulin	39.2-72.1	40.0-57.1
α-Lactalbumin	17.8-33.3	12.0-24.3
Serum albumin/Lactoferrin	5.1-21.5	4.0-5.71
Immunoglobulins	4.6-21.4	10.0-25.7

2.3 Carbohydrates

Lactose is the major milk sugar in the goat's milk; however, its concentration is lowered by 0.2-0.5% of cow milk lactose content (Ceballos *et al.*, 2009) [10]. Nevertheless, its concentration does not very much. Furthermore, lactose is thought to favor the absorption of minerals like calcium, magnesium, and phosphorus along with the utilization of vitamin D (Kalyankar *et al.*, 2016). On the other hand, the presence of oligosaccharides, glycopeptides, glycoproteins, and nucleotide sugars have also been reported in small amounts (Amigo & Fontecha, 2011) [5]. Oligosaccharides despite enhancing the sensory properties, investigations have also reported the manifestation of prebiotic properties of goat's milk oligosaccharides that enhances the probiotics viability and delivery capacities (Martinez-Ferez *et al*., 2006**;** Park *et al.*, 2007) [14, 41]. The various goat milk-derived oligosaccharides have been pictorially shown in Figure 1.

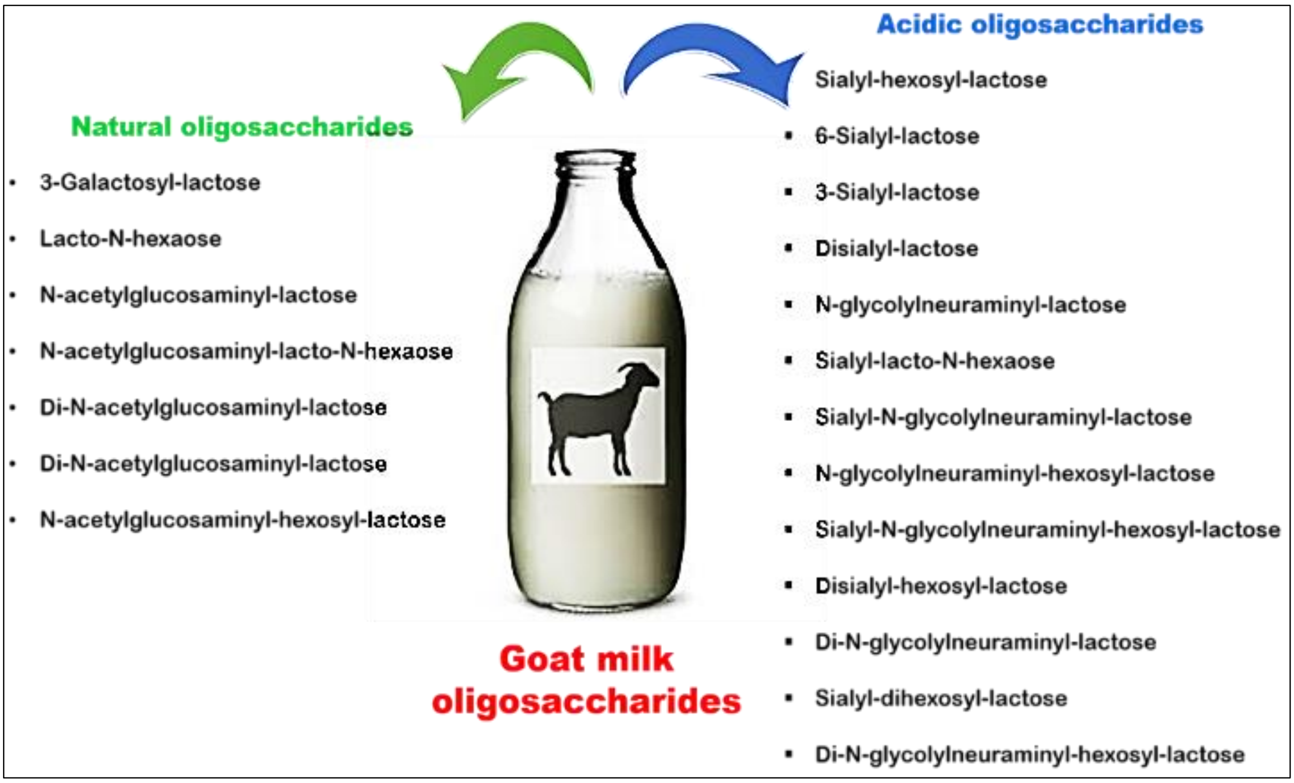

Fig 1: Goat milk-derived oligosaccharides

2.4 Minerals

Goat milk is mild salty in taste due to its higher ash content. The major minerals found in goat milk include Ca, P, Mg, K, and Na, while minor minerals are Mn, Zn, Fe, and Cu (Kumar *et al*., 2016) [28]. Amongst multiple vitamins, vitamin K was found at higher concentrations in goat milk (Mohsin *et al*., 2019) [34]. Although milk is a rich source of Ca and P, no significant variations were found regarding goat and cow milk as shown in Table 5. However, goat milk provides a more absorbable form of Ca and P that are needed for maintaining bone mineral density. It has been observed that goat milk has relatively lower levels of Na and S compared with bovine milk (Pal *et al*., 2017). However, human milk contains much less of these minerals with only one-fourth as much calcium and one-sixth as much phosphate. Among trace minerals, Zn was found at a greater amount in goat milk as compared to human milk (Park and Chukwu, 1989). Goat and cow milk contain significantly greater iodine contents than human milk, which would be important for human nutrition since iodine and thyroid hormones are involved in the metabolic rate of physiological body functions (Underwood, 1977) [49]. Indeed, the mineral content greatly varies among the individuals, breed, diet, and stage of lactation (Chavez-Servın *et al*., 2018) [12].

Table 5: Mineral profile (amount in 100g) of goat milk, cow milk and human milk (Park *et al*., 2007) [41].

Mineral	Goat milk	Cow milk	Human milk
Ca (mg)	134	122	33
P (mg)	121	119	43
Mg (mg)	16	12	4
K (mg)	181	152	55
Na (mg)	41	58	15
Cl (mg)	150	100	60
S (mg)	28	32	14
Fe (mg)	0.07	0.08	0.20
Cu (mg)	0.05	0.06	0.06
Mn (mg)	0.032	0.02	0.07
Zn (mg)	0.56	0.53	0.38
I (mg)	0.022	0.021	0.007
Se (µg)	1.33	0.96	1.52

2.5 Vitamins
It has been observed that goat milk is rich in vitamin A since beta-carotene is converted into vitamin A, and hence goat milk is whiter than the bovine milk. Goat milk is rich in niacin, thiamin, riboflavin, pantothenate. On the contrary, goat milk is significantly deficient in folic acid and vitamin E (Kalyankar *et al*., 2016). The various vitamins in goat milk have been pooled in Table 6.

Table 6: Vitamin content (amount in 100 g) of goat milk, cow milk and human milk (Park *et al*., 2007) [41]

Vitamin	Goat	Cow	Human
Vitamin A (IU)	185	126	190
Vitamin D (IU)	2.30	2.00	1.40
Thiamine (mg)	0.068	0.045	0.017
Riboflavin (mg)	0.21	0.16	0.02
Niacin (mg)	0.27	0.08	0.17
Pantothenic acid (mg)	0.31	0.32	0.20
Vitamin B6 (mg)	0.046	0.042	0.011
Folic acid (μg)	1.00	5.00	5.50
Biotin (μg)	1.50	2.00	0.40
Vitamin B12 (μg)	0.065	0.357	0.03
Vitamin C (mg)	1.29	0.94	5.00

3. Therapeutic attributes of goat milk (Figure 2)
3.1 Anti-allergic and better digestibility properties
Allergy to milk proteins, especially cow's milk, is an adverse reaction to milk ingestion, necessarily immunomodulatory and classified as IgE mediated, non-IgE mediated or mixed (Fiocchi *et al*., 2010; Koletzko *et al*., 2012) [19, 27]. Cow milk allergy is commonly found during the first 3 years of human life. It is due to the reason that the presence of α-S1-casein, β-casein, and β-lactoglobulin in milk causing allergy **(**Ruiter *et al*., 2006) [45]. Elsayed *et al*. (2004) [6] demonstrated that N and C-terminal peptides of cow's α-S1-casein (16-35 aa and 136-155 aa) have higher binding affinity for IgE, while the epitopes 17-36, 39-48, 69-78, 93-102, 109-120, 123-132, 139–154, 159-174, and 173-194 were recognized as IgE ligands in children (Vila *et al*., 2001) [50]. In contrast, investigations have shown that the usage of goat milk has resolved 30 and 40% of the cases (Haenlein, 2004) [21]. Haenlein, (2004) [21] reported that 40–100% of allergic patients were sensitive to cow's milk proteins and were able to tolerate goat's milk proteins. The genetic polymorphism that occurs in the proteins between the different species supports the potential use of goat milk as a substitute for cow's milk during allergic disease (Ballabio *et al*., 2011). Additionally, goat's milk has been shown to trigger innate and adaptive immune responses in the human system, and also inhibiting the endotoxin-induced activation of monocytes in the host (Jirillo and Magrone, 2014) [23].

The better digestibility of goat's milk in comparison with cow's milk is related to the differences in the fatty acids (FA) composition. The lower size of the fat globules in goat milk is one of the factors that increases its digestibility. In addition, the proportion of small-sized casein micelles is higher in goat's milk than that of cow's milk, which explains the better digestibility of goat's milk and its dairy products (Park *et al*., 2007) [41]. Goat milk contains a relatively lower amount of α-s casein and often has more αs2 than αs1-casein. Moreover, the β-casein and kappa-casein are more in the goat milk than cow milk, therefore weak gel is obtained which is beneficial for better digestibility (Lad *et al*., 2017) [29].

3.2 Immunomodulation
The immunomodulatory properties of goat milk can be attributed to the compounds like peptides, oligosaccharides that were reported to modulate host inflammatory cytokines (Daddaoua *et al*., 2006; Santosh *et al*., 2016) [14]. The milk can trigger innate and adaptive immune responses in the human body that can help fight against inflammation (Jirillo and Magrone, 2014) [23]. Lara-Villoslada *et al*. (2006) [30] reported that goat's milk oligosaccharides decrease intestinal inflammation in rats and contribute to the recovery of damaged colonic mucosa. In an *in vivo* murine model, goat whey inhibited the NF-κB p65 and p38 MAPK signaling pathways that subsequently down-regulated the gene expression of various pro-inflammatory markers such as IL-1β, IL-6, IL-17, TNF-α, iNOS, MMP-9, ICAM-1. Also, goat whey increased the expression of proteins such as mucins, occludin proteins that increases the gut barrier property (Araujo *et al*., 2017) [6].

3.3 Antiatherogenic property
Goat milk is rich in medium-chain triglycerides (MCT including fatty acid esters of caproic, caprylic and capric fatty acids. These MCT have shown a lowering effect on plasma cholesterol in rat models (Alferez *et al*., 2001) and also to inhibit cholesterol deposition in the tissues (Babayan, 2009) [8]. Consumption of goat milk triggers the release of nitric oxide (NO) blood cells that in turn reach the bloodstream via the lymphatic route, thus provoking vasodilatation and exerts a cardio-protective and anti-atherogenic effect (Tilahunzenebe *et al*., 2014). Furthermore, goat's milk contains less of the enzyme xanthine oxidase, an inflammatory marker enzyme that causes heart disease (Alférez *et al*., 2001) [2]. Moreover, several lines of evidence also suggested the ACE inhibitory potentiality, anti-oxidative property and cholesterol-lowering ability of goat milk-derived peptides and fats (Ibrahim *et al*., 2017; Moreno-Montoro *et al*., 2017; Kalyan *et al*., 2017) [22, 37] and therefore indicating their possible role in controlling coronary artery diseases (CVD).

3.4 Lactose intolerance
Lactose intolerance is a digestive disorder caused by the inability to digest lactose (vital milk sugar). Goat milk is an alternative source for people with lactose intolerance. Although goat milk has lactose, it has been hypothesized that the superior digestibility of goat milk relatively masks its intolerance effect (Johansson, 2011) [25], however, it needs to be further studied. Goat milk is more completely and easily absorbed than cow milk, leaving less undigested residue in the colon to ferment and cause the uncomfortable symptoms of lactose intolerance (Haenlein, 2004; Aliaga, 2010) [21, 3].

3.5 Overcomes dengue viral fever
Dengue, the most common major health problem (viral fever) in India, which is transmitted to humans by *Aedesaegypti* (Neuberger *et al*., 2016). Treatment of dengue fever typically involves the use of goat milk and milk products since they are rich in selenium (Se) (13.7 ng/mL). Nevertheless, the selenium (Se) concentration in the milk depends on several factors like feed, climatic conditions, and breed (Dael *et al*., 1992; Singh *et al*., 2016; Zhang *et al*., 2018) [48, 52]. The deficiency of Se has been positively correlated with the decrease in platelet count, which is a key marker to recognize the onset of dengue fever. Se has an anticlotting effect

whereas, thrombotic or pro-clotting effects are mainly observed due to the Se deficiency (Mahendru *et al*., 2011) [31].

3.6 Anticancer properties
Anti-carcinogenic property of goat milk has been studied against mammary and colon cancer in animal models, as well as *in vitro* human melanoma, colorectal and breast cancer cells (Ceballos *et al*., 2009; Johansson, 2011) [10, 25]. The mechanism by which conjugated linoleic acid (CLA) inhibits tumor development is not fully understood. Additionally, several lactic acid bacteria that are isolated from goat milk have also reported demonstrating anticancer effect (Mittu and Girdhar, 2015) [33] and therefore suggesting the use of goat milk-derived LAB for preparation of fermented milk product impart the same therapeutic properties that the bacterial strains possess.

3.7 Antimicrobial property
The total inhibitory effect of milk is generally greater than the sum of the individual antimicrobial effect of immunoglobulin and other defense proteins viz. lactoferrin, lactoperoxidase, lysozyme, and other peptides. Therefore, the synergistic effect of naturally occurring proteins and peptides provides the antimicrobial effect. In this regard, the lactoperoxidase was found has inhibitory action against a plethora of pathogens viz. *Vibrio cholera*, *Salmonella typhi*, *Klebsiella pneumoniae*, *Shigella dysenteriae*, and *Staphylococcus aureus* (Anonymous, 1998; Esmaeilpour *et al*., 2016; Moreno-Montoro *et al*., 2017) [17, 37]. Similarly, several antimicrobial peptides like isracidin, lactoferricin from goat milk have been isolated that were effective against several disease-causing and spoilage organisms (Atanasova & Ivanova, 2010) [7].

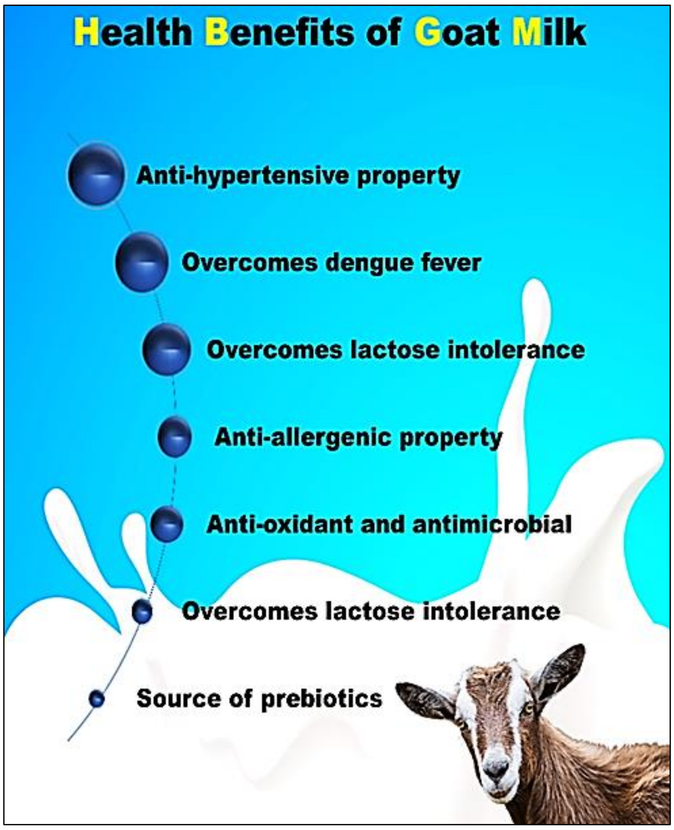

Fig 2: Overall health benefits of goat milk and milk products

4. Concluding remarks
To conclude, ample nutritional and health benefits of goat milk are the paramount factors that dragged the consumers to use goat milk and milk products as functional foods. The composition of goat milk does not reveal greater variations as compared to cow milk, whereas, it shares few similarities with human milk composition. Besides, the superior digestibility of goat milk is the key factor that led to extensive usage of goat milk as an alternative to cow milk for infants suffers from the shortage of mother's milk. In addition, several studies conducted on *in vitro* and *in vivo* animal models have demonstrated the positive health effects viz. anticancer, anti-inflammatory, antiatherogenic, anti-allergenic diseases and so on. According to the reviewed literature, goat milk and its products have the potentiality to act as nutraceuticals in combination with conventional medical treatment. However, further clinical trials are needed to explicate their therapeutic benefits.

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