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Potential of Non-Bovine Milk

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CONVENER : Dr M.S. Chauhan, ICAR-National Dairy Research Institute, Karnal, Haryana

EDITORS : Dr P.S. Birthal
Dr Malavika Dadlani

REVIEWERS : Dr Raghvendar Singh, ICAR-Central Sheep & Wool Research Institute, Avikanagar, Rajasthan
Dr N.V. Patil, ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan

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NASC, Dev Prakash Shastry Marg, New Delhi - 110 012
Tel: (011) 25846051-52; Fax: (011) 25846054
Email: naas-mail@naas.org.in; Web site: http://www.naasindia.org

Preface

The milk of the non-bovine species (goats, sheep, camel, and donkey) has several nutritional and therapeutic properties, and thus, can be an excellent functional food, and also a key ingredient in pharmaceuticals. It is the main source of biologically active biomolecules, such as caseins and alpha-lactalbumin that are antiviral and immune regulatory. The non-bovine milk being rich in high-quality protein, calcium, vitamins A and B12, zinc, and selenium, has considerable potential to contribute towards a healthy immune system.

India has many non-bovine milch species, well adapted to the harsh agro-climatic conditions of the plains and hills. Most often, these animals are raised by the marginalized people in the marginalized environments, primarily for meat and draught purposes; and have not been valued as producers of superfoods and pharmaceuticals. Their milk can be of use in the preparation of probiotic supplements and the production of bioactive peptides with bio-functional immune-boosting properties. These products are potent in imparting immunity to human beings against several diseases, including coronavirus disease. Since the chemical and microbial composition of milk influences human nutrition and health, the quality and techno-functional properties of non-bovine milk need to be investigated employing state-of-the-art technologies and catalogue these for quality, functionality, and safety, which are essential for the commercialization and exports of milk and milk products.

Given the importance of non-bovine milk, the National Academy of Agricultural Sciences (NAAS) organized a brainstorming session on June 29, 2020, to explore the potential for the development of non-bovine dairying and its linkages with the nutraceutical and pharmaceutical industries under the convenorship of Dr M.S. Chauhan. I thank Dr Chauhan and all the participants for their contribution in enhancing our understanding of the utility of non-bovine milch species. The observations and recommendations of the participants are synthesized and presented in this document. I also thank Dr Sunita Grover for her valuable comments on the earlier version of this document. My sincere thanks to Dr P. S. Birthal and Dr Malavika Dadlani for their editorial support in bringing the document in its present form.

(Trilochan Mohapatra)
President
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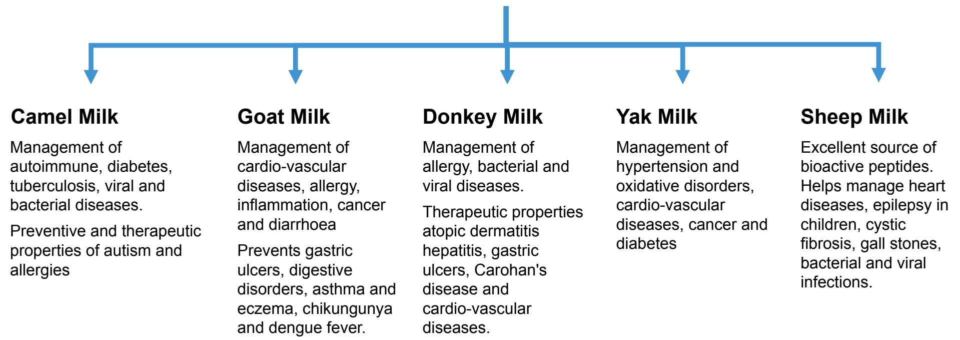
1. INTRODUCTION

India's dairy sector has witnessed tremendous growth in the past five decades — milk production increased from 21.2 million tonnes in 1970-71 to198.4 million tonnes in 2019-20, lifting the per capita annual milk availability from 112 kg to 407 kg (GoI, 2020). Cows and buffaloes are the main milch species, contributing close to 95% to the country's total milk production. There are many non-bovine species such as goats, sheep, camels, mares, and reindeer, whose milk possesses numerous therapeutic properties considered good for human health, but these species have not received much attention (Park and Haenlein, 2006). Their milk is characterized by a large amount of functionally active lipids, lactose, immunoglobulins, immune proteins, peptides, nucleotides, oligosaccharides, and metabolites. The milk also has unique chemical and microbial properties, which can be exploited for improving human health. For example, camel milk as a medicinal food, and donkey milk being hypo-allergenic, is suitable for infants.

Figure 1. Therapeutic properties of non-bovine milk



According to the Livestock Census 2019, the country has 148.88 million goats, 0.25 million camels, 74.3 million sheep, 0.06 million yaks, and 0.39 million mithuns (GoI, 2020). These animals are raised by the marginal farmers for their livelihoods in the degraded environments.

This paper deliberates on the nutritional and therapeutic properties of non-bovine milk to devise strategies for harnessing the milk potential of non-bovine species for human nutrition and also use in the pharmaceutical industry.

2. CHEMICAL COMPOSITION OF NON-BOVINE MILK

Milk composition can determine its nutritive value and suitability for its conversion into processed and value added products. The composition varies with animal species, breed, lactation order, health, and feeding regime. The nutritional composition of milk of non-bovine species is similar to that of cow milk, but the non-bovine milk has additional uniqueness in its chemical, biochemical, and physical properties that impart it distinct nutritional and therapeutic values.

Bovine milk differs from non-bovine milk in its constitution of proteins (casein and whey proteins). Casein to whey protein ratio in cow, goat, sheep, and buffalo milk is 80:20, and in horse milk 50:50 (Lara-Villoslada *et al.,* 2005). The dominant casein in camel, goat, and human milk is β-casein; α_{s1}, and β-caseins in horse milk; and α_{s1} in cow milk. Among whey proteins, β-lactoglobulin is the main protein in cow, buffalo, goat, and sheep milk, and it is absent in camel milk (Hinz *et al.,* 2012). And the concentration of α_{s1}-casein correlates strongly with the yield of processed products — a higher concentration of α_{s1}-casein yields reprocessed products, particularly cheese.

The pH of camel milk is the lowest, and that of horse milk is the highest. Titratable acidity of the camel milk is also lower as compared to the milk of cow, buffalo, sheep, and goat, but it is higher than that of the milk of donkey and horse. Heat coagulation time (HCT)-pH curve for cow and goat milk has distinct maximum and minimum, while camel milk shows no such observation. The heat stability of milk depends on the heat-induced complexation between casein (k-casein) and whey protein (β-lactoglobulin). Thus, the lower heat stability of the camel milk owes to its lower k-casein and also because of the lack of β-lactoglobulin.

Milk fat digestibility is influenced by the size of fat globules, which is the largest for buffalo milk and the smallest for camel, sheep and goat milk (Barłowska *et al.,* 2011). Smaller fat globules lead to a homogeneous mixture with a larger surface area for the lipase enzyme to act, which has a direct role in fat digestibility. Goat and camel milk have poor creaming ability as these are deficient in agglutinins that favour the clustering of fat globules. Thus, the digestibility of the naturally homogenized goat milk is better than homogenized (mechanically processed) bovine milk.

The fatty acid profile of goat and sheep milk shows a significantly higher level of short (C4:0 - C8:0) and medium-chain fatty acid (C10:0 - C14:0) than of cow milk. Lipase enzyme acts efficiently on ester linkages of short and medium-chain fatty acids than of the long-chain fatty acids; thus, goat and sheep milk is digested easily. The “goaty” flavour of the goat and sheep milk is due to the higher content of caproic, caprylic, and capric acids (Barłowska *et al.,* 2011).

Lactose, the most constant component of milk, is higher in the milk of horses, donkeys, and human beings. Vitamin C is much higher in horse and camel milk as compared to the cow, buffalo, sheep, goat, and ass milk. Vitamin A content is higher in goat milk than in cow milk; as β-carotene in the milk is converted into vitamin A (Kalyankar *et al.,* 2016). Sheep milk is richer in most vitamins. The level of immunoglobulins (IgG), lysozyme, and lactoferrin are higher in camel milk than in milk of cow, buffalo, sheep, and goat.

Information regarding the chemical composition of milk and milk products of non-bovine species is limited. Hence, characterization of milk constituents of non-bovine milk needs to be taken up on priority, and this will go a long way in the diversification of milk for the development of healthier and nutritious products.

3. MICROBIAL DIVERSITY IN NON -BOVINE MILK

Many diverse groups of micro-organisms — health-promoting, spoilage-causing, technology-relevant, and disease-causing bacteria — are present in milk. Limited data are available on the microbiological quality of non-bovine milk. According to some latest metagenomic studies, the non-bovine milk harbours diverse functional microbiota (Quigley *et al.,* 2013; Li *et al.,* 2017) — technologically relevant and potential probiotic bacteria along with pathogenic and spoilage bacteria. Milk microbiota studies would facilitate the discovery of new bacteria with potential health and technological importance along with pathogenic and spoilage groups. Zhang *et al.* (2017) investigated microbial diversity in raw milk of Saanen and Guanzhong goats in China. They reported *Proteobacteria* as the predominant phylum, accounting for 71.31% of all phyla identified in milk from two breeds, and *Enterobacter* was the predominant genus (24.69%) within the microbial community. Microbial alpha diversity from Saanen goat milk was significantly higher than from Guanzhong goats. Recently, Russo *et al.* (2020) observed that cold storage reduces microbial biodiversity of donkey milk; encouraging *Pseudomonas* spp. The microbial communities might negatively affect the quality of raw products and their technological transformation. They pointed out that the occurrence of microbial species belonging to biosafety risk group 2 in the fresh milk may pose moderate safety concerns.

Many traditional fermented products are prepared from raw milk of non-bovines; hence safety of such products becomes important. Metagenomic profiling of Dhanaan (prepared from raw camel milk) showed both technologically relevant (*Streptococcus, Lactococcus, Weissella*) and pathogenic (*Klebsiella, Enterobacter, Acinetobacter, Clostridium*) bacteria (Berhe *et al.,* 2019). Similarly, another traditional product Suusac from camel milk also contained technologically relevant (*Lactococcus lactis, Lactobacillus helveticus, Streptococcus lutetiensis*) and pathogenic (*Streptococcus agalactiae, Klebsiella pneumoniae Escherichia coli*) bacteria (Maitha *et al.,* 2019).

Milk microbiota is influenced by genetic and environmental factors also. Therefore, profiling of milk microbiota using conventional culture-based methods may not be an effective way but coupling with culture independent methods will yield better results.

4. NON-BOVINE MILK METABOLOMICS

Sacco *et al.* (2009) reported high glycerol and sugar content in cow milk samples from Southern Italy than in the samples from countries of Central East Europe. Citrate, lactate, and protein content in sheep milk, valine, and glycine content in goat milk have been used as biomarkers to differentiate these milk (Scano *et al.,* 2014). Caboni *et al.* (2019) also reported differences in the metabolite profiles of sheep and goat milk. Sheep milk has an abundance of arabitol, citric acid, α-ketoglutaric acid, glyceric acid, myo-inositol, and glycine, while goat milk has a higher level of mannose-6-phosphate, isomaltulose, valine, pyroglutamic acid, leucine, and fucose. Citrate, choline, carnitine, and lactose content are linked with the coagulation properties of milk (Sundekilde *et al.,*2011). Ahamad *et al.* (2017) reported that camel milk contains a higher level of alanine and valine amino acids as well as higher fatty acids and fructose responsible for a highly nutritious diet, and having heavy metals within safe limits.

There is hardly any study from India on the microbiological quality, diversity, and metabolite profiling of milk from non-bovine animals. India has varied climatic regions, ranging from tropical in the south to temperate and alpine in the Himalayas, which has led to diversity in non-bovine animals and fodder crops and seasons. Diet and season may also influence milk microbiota and metabolites profile. Therefore, exploring non-bovine composition (both chemical and microbiological) with the 'Omics' approach is an opportunity to discover active biomolecules and unique microbes having the potential to improve health. Understanding of the traditional fermented products, prepared from non-bovine milk, chemically and microbiologically will enhance the quality of the products for commercialization.

5. NUTRITIONAL AND THERAPEUTIC VALUES OF NON-BOVINE MILK

Goat milk

India has 148 million goats, producing about 6.19 million tonnes of milk, that accounts for about 37% of the global goat milk production. This seems to be a rough estimate because of the scattered population of dairy goats (CIRG, 2014). Goat milk in India is primarily for household consumption. Goat is known as "*the cow of the poor people*", and has been the most reliable source of livelihood for them since its domestication during the Neolithic Age.

Although India ranks first in the population of goats and their milk production, goat farming is subsistence-oriented (Agnihotri and Rajkumar, 2007). The most organized market for goat milk is in Europe, especially in France, where manufacturing cheese from goat milk is a specialized activity and is high in demand. New dairy industries based on goat milk are gaining importance in China, the United States of America, and New Zealand because of the growing consumer demand, remunerative prices, and a safeguard against climate change (Miller and Lu, 2019).

The main outputs from goat: meat, milk, and fibre. But, the goats are primarily reared for meat, and milk as an adjunct. Goat milk lacks ubiquitous acceptability and fetches less than half the price of cow and buffalo milk because of its "strong, smelly, salty or sweet" properties that are less acceptable to consumers. Nevertheless, consumer preference for goat milk is increasing gradually due to the growing awareness about its nutraceutical and therapeutic properties. Digestibility of goat milk proteins is better than of the bovine milk proteins, as during acidification it forms *softer* clots in the *stomach* that are efficiently digested by proteases (Park, 2007).

Goat milk is richer in vitamin A, vitamin B_1, vitamin B_2, vitamin B_5, calcium, phosphorous, zinc, potassium, and selenium than cow milk (Raynal-Ljutovac *et al.,* 2008). It contains 13% more calcium, 25% more vitamin A, 134% more potassium, 3 times more niacin, and 4 times more copper (Posati and Orr, 1976). Goat milk contains a higher proportion of medium-chain triglycerides (36% in goat milk versus 21% in cow milk), i.e., caproic (C6:0), caprylic (C8:0), and capric (C10:0), which are partly responsible for its characteristic "goaty" odour, and this also imparts it medicinal value. Goat milk has higher monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA), and medium-chain triglycerides than cow milk; which are beneficial to humans especially the ones suffering from cardiovascular diseases (Alonso *et al.,* 1999).

Another characteristic of goat milk is the presence of a complex array of nucleotides. These nucleotides supposedly facilitate maturity in the immune system of this milk-fed offspring and thus, can be an adjuvant for infant formulae (Schallera *et al.,* 2007). Goat milk nucleotides are involved in lipoprotein metabolism also, increasing high-density lipoproteins (HDL) and synthesis of apolipoprotein A1 and Apo A1 V in pre-term infants as well as long-chain polyunsaturated fatty acid (PUFA) in neonates (Schallera *et al.,* 2007). Taurine, glycine, and glutamic acid are major free amino acids present in the milk (Rutherford *et al.,* 2008). Taurine is about 20 to 40 times higher than cow milk. Goat colostrum and milk are rich in polyamines; higher than in milk of other mammals. Polyamines are important for optimal growth, gastrointestinal tract (GIT) cell function, and maturation of GIT enzymes, and are found to reduce food allergy in infants (Dandrifosse *et al.,* 2000).

Oligosaccharides in goat milk also drew attention and these have been quantified and characterized (Martinez-Ferez *et al.,* 2006). Their amount is much higher in goat milk than in cow milk (4-5 times) and sheep milk (10 times); but much lesser than in human milk. These oligosaccharides are complex and have similarities in profile with human milk, and possess prebiotic effect, and stimulate gut *Bifidobacterium* and *Lactobacillus* spp. (Boehm *et al.,* 2002). Goat milk oligosaccharides have many functional properties — antiadhesive, antimicrobial, immune modulators, intestinal epithelial cell response modulation, and nutrient provider for neonatal brain development and also for the growth of desired gut microflora (Lima *et al.,* 2018). Thus, goat milk can be an attractive natural source of human-like oligosaccharides for infants.

The significance of goat milk in infant diet is on account of its easier digestibility and less allergy-causing than cow milk. The absence of agglutinin combined with higher short and medium-chain fatty acids prevents clustering of fat globules, thus making it easier to be digested. Goat milk also has anti-diabetic, anti-allergenic, anti-cancerous, anti-inflammatory, anti-diarrheal, and malabsorption syndrome properties (Lara-Villoslada *et al.,* 2006; Johny *et al., 2009;* Abbas *et al.,* 2015; Zhang *et al.,* 2015b). Recently, goat milk has been found to contribute towards increasing platelet counts of patients suffering from viral diseases like chikungunya and dengue fever; selenium deficiency and decreased platelet count are the main complications in dengue fever (Mahendru *et al.,* 2011).

Sheep milk

Sheep (ewes) are raised for wool, meat, and milk. In India, sheep milk production is about 0.2 million tonnes. Globally, sheep contribute about 1.3% to total milk production, although its contribution is higher in Africa (6.6%). Sheep milk has a higher specific gravity, viscosity, titratable acidity, refractive index, and lower freezing point as compared to cow milk (Haenlein and Wendorff, 2006). Sheep milk contains higher medium-chain triglycerides (MCT) and PUFA content than cow milk. It is found superior to cow milk in all 10 essential amino acids. Sheep milk has a sweet and soft flavour and aroma and a creamy texture due to small fat globules, thus making it easily digestible (Park *et al.,* 2007). The distinctive flavor is also reported in sheep milk butter and cheese (Jooyandeh and Aberoumand, 2010).

All fresh or soft-type processed products — fluid milk, fermented milk, yogurt, ice -cream, butter, and soft cheeses—are from sheep milk. Sheep milk is mainly used for fine cheese varieties, yogurt, and whey cheeses (Haenlein and Wendorff, 2006). Traditionally, the production of cheeses has been the greatest market for sheep milk throughout the world. Sheep milk is found superior to buffalo, cow, and goat milk. Being the richest source of butyric acid (C4:0), Omega 3 fatty acid, conjugated linoleic acid, and α-linolenic acid, sheep milk has been proven beneficial against cancer, coronary heart disease, and osteoporosis; and it also stimulates the immune system. Conjugated linoleic acid (CLA) has multiple functional properties. The milk is being used in anti-aging formulations and therapeutic use in psoriasis and skin eczema. It has positive effects on bone structural integrity and bone health due to more availability of calcium and phosphorus. Consumption of sheep milk or its derivatives can boost intake of protein, carbohydrates, beneficial fats, essential minerals, and important vitamins. Due to the limited period of milk production in a year, sheep milk and related products are more expensive (Park *et al.,* 2007).

Camel milk

Camel —alone in all creatures— is a distinct animal, which can survive in harsh environments. In India, the production of camel milk is at 23,000 tonnes a year. Camel produces milk round the year and in larger quantity due to its longer lactation length of 14-16 months. Camel milk called "*white gold of the desert"* is almost similar to human milk, and is low in cholesterol and sugar, and is high in minerals (sodium, potassium, iron, copper, zinc, and magnesium), vitamin C, lactoferrin, lactoperoxidase, immunoglobulins, and lysozyme (Yadav *et al.,* 2015). The milk also contains a high concentration of anti-inflammatory proteins and insulin-like proteins with positive health benefits. Thus, camel milk finds application in several health concerns; gastrointestinal disorders, diabetes, food allergy, hypercholesterolemia, hepatitis C and B, low immunity, psoriasis, cancer, autism, and tuberculosis (Kaskous, 2016).

The high proportion of mono-, and poly-unsaturated fatty acids and vitamin-rich composition of the milk improve carbohydrate metabolism (Konuspayeva *et al.,* 2008). The fermented camel milk has an enzyme, Angiotensin I-converting enzyme(ACE), which facilitates in the digestion of milk proteins (Quan *et al.,* 2008). Many scientific studies have indicated that the application of camel milk and camel urine (drinking cure) had led to a reduction in the growth of cancer cells (Magjeed, 2005). It has been demonstrated that camel milk has a therapeutic effect on Autism (Al-Ayadhi and Elamin, 2013). Camel milk has no β-lactoglobulin that causes allergic symptoms (Hinz *et al.,* 2012). Similar to human milk, camel milk has approximately double β-casein and approximately five times immunoglobulins as compared to cow milk (Hailu *et al.,* 2016).

Camel milk has the following characteristics: strong immune-modulatory, antioxidative, antibacterial, antiviral, antifungal, anti-hepatitis, hypoglycemic activity and anti-cancerous. It helps in prevention of aging and autoimmune diseases and also good for treating paratuberculosis (Jilo and Tegegne, 2016). Agrawal *et al.* (2011) had conducted a randomized controlled trial on camel milk's effect on glycemic control and insulin requirements in patients with Type-I diabetes and reported camel milk safe and efficacious in improving long-term glycemic control, besides significant reduction in insulin intake.

Equine milk

Equine (donkey) milk differs from the milk of conventional dairy species. The equid mammary gland has a low capacity (maximum 2.5 L), and a part of the milk needs to be left for the foal, and milking may be carried out two or three hours after separation from the foal. To increase milk supply, dairy equids may need to be milked repeatedly each day (Salimei and Fantuz, 2012). A female gives between 0.5 and 1.3 litres of milk a day for about 6–7 months.

Donkey milk is used as a substitute for human milk in many countries. Nowadays, consumer interest in donkey milk is increasing in European countries due to its compositional similarity to human milk, and good tolerability and palatability. Hence, in western countries, donkey dairies are emerging to produce an alternative milk source for human infants. There is enhanced interest of consumers in India's southern states also; although there are no official reports or published data on its production, quality, and hygiene.

As compared to bovine milk, the donkey milk contains less fat, protein, and inorganic salts but more lactose with a concentration closer to human milk. Lactose is a source of readily available energy and it makes the milk sweet, palatable, and acceptable to children. The pH of donkey milk, as well as human milk, is neutral or slightly alkaline, probably due to low caseins and phosphates (Pal *et al.,* 2018). Some researchers have speculated that smaller native milk fat globules may have utmost digestive parameters due to the larger surface available for lipase action (Raynal-Ljutovac *et al.,* 2008). Fat globules have been found lesser in donkey milk than in cows, goats, and sheep milk (Martini *et al.,* 2013). Equine milk doesn't cream due to the small amount of cryoglobulin (agglutinins), a protein that adsorbs onto fat globules because of reduced temperature; and hence agglutination of fat globules occurs very slowly (O'Mahony and Fox, 2014). The main salts in the milk are calcium, phosphorus, potassium, sodium, and magnesium, and their concentration, except that of potassium, is higher in the donkey milk than in the human milk, but considerably lower than in the milk of cows, buffaloes, goats, and sheep (Salimei and Fantuz, 2012). Donkey milk also contains anti-microbial proteins; lysozyme and lactoferrin. The lactoferrin content of the donkey milk is between the lower values of cow milk and the higher values of human milk. Lysozyme is present in large amounts, ranging from 1.0 mg/mL to 4 mg/mL, and it is highly thermostable and resistant to acid and protease and may play a significant role in intestinal immune response (Tidona *et al.,* 2011).

The donkey milk possesses some unique attributes as reported in the literature (Guo *et al.,* 2007; Aspri *et al.,* 2017; Bhardwaj *et al.,* 2020; Derdak *et al.,* 2020). It is low in fat, and hence it is considered good for cholesterol management.

Presently, there is no breeding policy for donkeys in India. Selective breeding of donkeys can help to enhance their milk production potential. Even the mechanism of tolerance of donkey milk has not yet been fully evaluated; it is rational to hypothesize that its reduced allergenic properties can be related to structural differences of its protein component as compared to cow milk.

The high lactose content also stimulates intestinal absorption of calcium, which is important for bone mineralization and the development of the nervous system in infants (Schaafsma, 2003). Moreover, high lactose content suggests its use for probiotic purposes (Coppola *et al.,* 2002); as this is a perfect substrate for the accurate development of intestinal lactobacilli. The fat content in donkey milk has been found negligible (Pal *et al.*, 2016; Bhardwaj *et al.,* 2020); and hence, the milk is termed as natural defatted milk. Thus, milk drinks may have an immense future potential for therapeutic applications.

Donkey mammary secretions contain human-like leptin at levels closer to human milk (3.35 to 5.32 ng/mL). The bioactive peptides— insulin-like growth factor 1, ghrelin, and triiodothyronine — are also found in frozen donkey milk. These molecules, and many others present in human milk, are increasingly receiving attention for their potential direct role in regulating food intake, metabolism, and infant body condition. Donkey milk is used as natural hypo-allergenic milk, as it is tolerated by about 90% of infants with varied food allergies; breast' milk protein allergy, a common food allergy in childhood with a prevalence of approximately 3% during the first 3 years of life (Salimei and Fantuz, 2012).

Since time immemorial, donkey milk has been known for its unique therapeutic values. It has remedial value as a restorative agent for metabolic diseases. It can be used in the cosmetics industry. It is the most expensive milk in the world. Its value-added products have tremendous potential, in the form of drinks for sports persons because of it being low in fat and cholesterol and high in energy.

In India, donkeys are raised by landless and marginal farmers for transportation of goods at short distances (e.g. in brick kilns) and by nomads as pack animals. If donkey owners are made aware of the nutritional and therapeutic properties of milk, equine husbandry can become an excellent source of income for them.

Yak milk

Yak (*Poephagus grunniens*), the lifeline of highlanders, is a unique bovine species adapted to harsh climates of high altitudes. Yak milk has a golden rich colour and has a sweet fragrance. In India, yak plays a major role in the livelihood of pastoral nomads in the foothills of the Himalayas. Its population in India is approximately 58,000; distributed mainly in Ladakh, Jammu and Kashmir, Arunachal Pradesh, Sikkim, Himachal Pradesh, West Bengal, and Uttarakhand. Globally, China has the largest number of yaks, approximately 14 million, almost 95% of the total yaks in the world (He *et al.,* 2011). Yak is the third-largest contributor to total milk production after cow and buffalo (Zhong *et al.,* 2006). Milk of yak is creamy white, thick, sweetish, fragrant, and rich in proteins, fats, lactose, minerals, and totals solids. It contains 15.63-19.63% total solids with 5.29-8.73% fats, 3.45-4.27% proteins and 0.64-0.82% ash (NRCY, 2018). In general, yak milk has a higher nutrient density and is loaded with omega 3 fatty acids, amino acids, and antioxidants, besides vitamins and minerals (Guo *et al.,* 2014). Yak milk is mostly converted into traditional products like *chhurpi* (wet cheese) and *Mar* (butter), and a small proportion of it is used for butter tea, consumed by the locals. Highlanders though do not consume vegetables or fruits throughout the year, yet show no obvious signs of nutrient deficiency. This raises the question of how highlanders can maintain their health under these extremely stressful long cold winters while consuming a diet of such a simple composition. It indicates that the daily ingestion of yak milk-derived products contributes to their well-being. The varied products are a rich source of conjugated linoleic acid and vaccenic acid. The relative richness of nutritional and biologically active ingredients in yak milk and its products is an excellent example of how an indigenous diet may have enabled these people to adapt and live healthy for thousands of years in extreme environments. Several studies have also reported on anti-inflammatory, anti-oxidative, anti-hypoxia, and anti-fatigue properties of yak milk (Mao *et al.,* 2011; Kumar *et al.,* 2013; Zhang *et al.,* 2014, 2015a). The superiority of yak milk may have also been associated with the grazing practices followed on high-altitude and low altitude pastures during transhumance. Besides providing nutrition to the highlanders, yak milk has a huge potential to improve the economy of the highlander farmers through value addition. Therefore, the untapped potential of yak milk can be explored by linking farmers to markets.

Mithun milk

Mithun (*Bos frontalis),* also known as "*Cattle of Mountains*" found in the north-eastern hill region of India is a semi-domesticated species reared primarily for meat. Mithun produces around 1 to 1.5 kg milk per day. However, it is nutritionally superior to the milk of any other domesticated species because of its high fat (8 to 13%), solid-not-fat (18 to 24%), and protein (5 to 7%). Physicochemical characteristics of mithun milk, studied from 0 to 13 days *post-partum,* showed day 0 colostrum as golden-yellow with pH 6.28, specific gravity 1.0599, and relative viscosity 7.25 (Nath and Verma, 2000; NRCM, 2018). It is very rich in total solids (41.60%) and protein (38.51%), but poor in fat (2.05%) and lactose (1.04%). With increased *post-partum* days, the physicochemical characteristics of mithun milk change and become stable from 10 days *post-partum.* Mid-lactation milk is yellowish-white with pH, specific gravity, and relative viscosity of 6.68, 1.0487, and 1.40, respectively. The percentage of total solids, fat, and lactose in whole milk is 22, 10.43, 9.65, and 3.50, respectively. Casein predominates in milk from 3 days *post-partum*. Different casein fractions are similar in early-lactation and mid-lactation milk but not so with whey protein fractions. Immunoglobulin predominates in the early-lactation milk and β-lactoglobulin in the mid-lactation milk.

Mithun can be promoted as a milch animal in high hills. Its milk can be used for the preparation of different value-added milk products such as paneer, sweets, ghee, cream, curd, and cheese.

6. VALUE-ADDED PRODUCTS FROM NON-BOVINE MILK

Non-bovine milk is emerging as a preferred choice as a specialty food due to its nutritional and health-promoting properties. The goat and camel milk are being explored as an efficacious matrix for probiotics. The probiotic non-bovine fermented foods are being analyzed for the prevention of allergies, autism, diabetes, etc. Goat and sheep milk for cheese-making is increasing worldwide. Interest in goat milk yoghurt is also on the rise because of its easy digestibility despite its soft texture and reduced yield. The composition of goat milk influences the yield and texture of cheese. Moreover, it also affects the quality of acid-induced curd of yoghurt. Different goat milk products like dry whole milk, dried granulated milk, condensed goat milk, fruit yogurt, cheese, butter and butter oil, cultured goat cream butter, ice-cream, whey protein concentrate (WPC), evaporated milk, traditional Indian products and Turkish butter known as Yak have been reported (Park and Guo, 2006a,b; Pandya and Ghodke, 2007). Several cosmetic beauty products are also being produced from goat milk, including soaps, creams, body lotion, shampoos, after-shave lotions, and hair conditioners (Ribeiro and Ribeiro, 2010). The characteristics of fatty acids caproic and caprylic acids in the milk help enhancing skin permeability (Wongpayapkul *et al.,* 2006).

Sheep milk contains more solids (15-16%) as compared to cow or goat milk, and thus is ideal for making ice cream, dried milk, cheese, and yoghurt. Sheep milk is extensively used for making cheeses and in higher quantities because of reduced synergies of whey and higher moisture. Higher content of whey in cheese leads to acidic and bitter flavour in cheese after ripening. Optimal solids in sheep milk give proper body and texture to yoghurt without the addition of any stabilizers. The high protein, fat, calcium, and casein makes it an excellent matrix for cheese production (Barłowska *et al.,* 2011). Sheep milk cheeses are the feta of Greece; Roquefort of France; Manchego of Spain; Serra da Estrela from Portugal; Pecorino Romano (the Italian word for sheep is *Pecora*), pecorino Sardo, and ricotta of Italy; Pag cheese of Croatia; Ġbejna of Malta; and Gomolya of Hungary; and Bryndza (*Slovenská bryndza* from Slovakia, brânza de burduf from Romania and *Bryndza Podhalańska* from Poland). In Greece, yogurt is also made from sheep milk.

Camel milk is a superfood enriched with minerals and has a high nutritive value. Camel milk is rich in Vitamin B3 that supports the functioning of the digestive system, skin, and nerves. Camel milk contains five times more vitamin C compared to cow milk, which is anti-infectious. Camel milk is processed into fermented milk, pasteurized milk, butter, and cheese. Its urine (traditionally used for ear infection, water belly and some kind of dermatitis) and dung are also valuable. Camel milk is a *natural pharmacy*, and can have tremendous potential in combating several diseases. Several products have been developed from camel milk,— ice-cream, *kulfi*, fruit flavoured milk, cheese, nuggets, whey drinks, paneer, *Sandhesh, peda, burfi* and dry milk powder.

Yak milk is processed into several commercially viable value-added milk products such as *paneer*, low-fat *paneer*, curd/yoghurt, cream, butter, ghee, whey beverage, *chhurpi*, *churkam* (hard cheese), and cheese. Several value-added mithun meat products have also been developed besides paneer, yoghurt, and dry milk powder.

Since donkey milk is very close to human milk and naturally hypoallergenic, it can be frozen, dried, or spray-dried and used upon reconstitution. It is also used for the preparation of chocolates, cookies, candies, etc. And is also used for soap-making, cosmetics, and antibacterial creams.

Milk-derived bioactive peptides (either released during digestion in the gut or during product fermentation by lactic acid bacteria) have proven as potential ingredients for addition into health foods. These milk-derived peptides from cow, goat, sheep, buffalo, and camel milk exhibit multiple bioactive properties — antimicrobial, immunomodulatory, antioxidant, antihypertensive, antithrombotic, opioid, hypo-cholesterolemic, anti-appetizing, etc. The biological functions exhibited by these peptides during gastrointestinal digestion need to be evaluated for product formulation. To transfer potent functional bioactive properties of these peptides from non-bovine milk into food and clinical applications needs to be taken up.

7. RECOMMENDATIONS

The value added products from the non-bovine milk have shown tremendous potential in the national and international markets and may hold the stature of the future superfoods.

- Comprehensive characterization of milk bioactive molecules as well as *in vitro* produced bioactive peptides of commercial value needs to be taken up on priority.
- Research on 'Non- bovine Milkbiome and Metabolome" should be intensified in the country to work on collating information on microbiological profiles of all non- bovine species using 'metagenomics' and 'culturomics' approaches.
- A comprehensive catalogue and culture collection of milk microbiota (spoilage-, pathogenic-, technology-relevant bacteria and probiotics) and whole genome sequencing of selected bacterial species (antibiotic and heavy metal resistance genes, toxic, virulent and beneficial genes) are required to strengthen the sector.
- Non-bovine milk and milk products being nutritionally superior have high commercial and economic value. Hence, identification of unique metabolites to be used as biomarkers for monitoring quality is important.
- There is a need to develop diagnostics based on differentiating biomarkers to have check on adulteration of any non-bovine milk from that of bovine milk in the market.
- Develop dairy entrepreneurship and mini-dairies for non-bovine milk. E-commerce platforms can also be used for marketing non-bovine milk.
- Provide financial support for developing value chain of non-bovine milk.
- Involve ICMR to establish therapeutic value of non-bovine and to recommended it for management of diabetes mellitus, allergy, autism, respiratory tract infections and immunomodulation.

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LIST OF PARTICIPANTS

1. Dr T. Mohapatra, President, NAAS, New Delhi
2. Dr A.K. Srivastava, Vice President, NAAS, New Delhi
3. Dr Anil K. Singh, Secretary, NAAS, New Delhi
4. Dr P.K. Joshi, Secretary, NAAS, New Delhi
5. Dr Kusumakar Sharma, Editor, NAAS, New Delhi
6. Dr P.S. Birthal, Editor, NAAS, New Delhi
7. Dr M.S. Chauhan, Director, ICAR-NDRI, Karnal, Haryana
8. Dr Sumit Arora, Principal Scientist, ICAR-NDRI, Karnal, Haryana
9. Dr T.K. Datta, Principal Scientist, ICAR-NDRI, Karnal, Haryana
10. Dr Y.P. Gadekar, ICAR-CS&WRI, Avikanagar, Rajasthan
11. Dr Sunita Grover, ICAR-NDRI, Karnal, Haryana
12. Dr Devendra Kumar, Scientist, ICAR-NRC Camel, Bikaner, Rajasthan
13. Dr Praveen Malik, Animal Husbandry Commissioner, Government of India, New Delhi
14. Dr R.K. Malik, Ex- Joint Director, ICAR-NDRI, Karnal, Haryana
15. Dr Bimlesh Mann, ICAR-NDRI, Karnal, Haryana
16. Dr A. Mitra, Director, ICAR-NRC Mithun, Nagaland
17. Dr B. Murugan, TANUVAS, Chennai, Tamil Nadu
18. Dr Yash Pal, Director, ICAR-NRC-Equines, Hisar, Haryana
19. Dr Vikas Pathak, DUVASU, Mathura, Uttar Pradesh
20. Dr Vijay Paul, Principal Scientist, ICAR-NRC Yak, Dirang, Arunachal Pradesh
21. Dr V. Rajkumar, ICAR-CIRG, Makhdoom, Uttar Pradesh
22. Dr Y.S. Rajput, ICAR-NDRI, Karnal, Haryana
23. Dr K.P. Ramesa, SRS, ICAR-NDRI, Bengaluru, Karnataka
24. Dr Latha Sabikhi, ICAR-NDRI, Karnal, Haryana
25. Dr A. Sahoo, Head, Animal Nutrition, ICAR-CS&WRI, Avikanagar, Rajasthan
26. Dr R.K. Sawal, Director, ICAR-NRC Camel, Bikaner, Rajasthan
27. Dr A.K. Singh, Principal Scientist, ICAR-NDRI, Karnal, Haryana

28. Dr R.K. Singh, Director, ICAR-IVRI, Izatnagar, Uttar Pradesh
29. Dr Rameshwar Singh, VC, BAU, Bihar, Patna
30. Dr R.R.B. Singh, Joint Director, ICAR-NDRI, Karnal, Haryana
31. Dr Dheer Singh, Joint Director, ICAR-NDRI, Karnal, Haryana
32. Dr M.K. Singh, ICAR-CIRG, Makhdoom, Uttar Pradesh
33. Dr B.N. Tripathi, DDG (AS), ICAR, New Delhi
34. Dr A.K. Tyagi, ICAR, New Delhi
35. Dr A.K. Verma, Scientist, ICAR-CIRG, Makhdoom, Uttar Pradesh
36. Dr Shipla Vij, ICAR-NDRI, Karnal, Haryana
37. Dr Raghvendra Yadav, Director, ICAR-CS&WRI, Avikanagar, Rajasthan

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Note: The designations and affiliations of the participants are as on date of BSS

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