Milk from minor dairy species

– Composition, processing and microbial aspects

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Milk from minor dairy species – Composition, processing and microbial aspects

Mjölk från andra arter – Sammansättning, tillverkning och mikrobiella aspekter

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Abstract

Milk plays an important part of the diet all around the world and 99 % of the milk consumed by humans comes from bovine, buffalo, sheep, and goat. In addition, some other species are used for milk production, so called minor dairy species. This literature review focused on six minor dairy species, i.e. horse, donkey, dromedary camel, red deer, reindeer and moose. Research and other relevant information about the milk's nutritional value, products made from the milk and their manufacture, potential for future product development, microbial content of the milk and food safety aspects were examined. A wide range of products, e.g., cheeses, fermented alcoholic drinks and ice cream made from milk of minor dairy species were found. The consumption is mainly connected to isolated communities in developing countries but there is also a small, commercial and industrial sector for milk products from minor dairy species. The nutritional content shows great varation between milk from minor dairy species. Protein and fatty acid composition are important factors in the dairy food production and impact which products and processing methodologies are viable. Microbial content of these milks and products is also an important aspect from both a production and food safety standpoint.

Keywords: Minor dairy species, equine milk, horse milk, mare milk, donkey milk, red deer milk, camel milk, reindeer milk, moose milk, dairy products

Sammanfattning

Mjölk utgör en viktig del av kosten i hela världen och 99 % av mjölken som konsumeras av människor kommer från ko, buffel, får och get. Därutöver finns det även andra, mindre vanliga arter vars mjölk används för human konsumtion. Denna litteraturstudie fokuserade på sex arter: häst, åsna, dromedar, kronhjort, ren och älg. Forskning och annan relevant information gällande mjölkens näringsvärde, produkter gjorda på mjölken, tillverkningsmetoder, potential för nya livsmedel, mjölkens mikrobiella innehåll och aspekter kring livsmedelssäkerhet undersöktes. Konsumtion av mjölk från mindre vanliga arter sker främst i isolerade samhällen i utvecklingsländer men det finns en liten kommersiell sektor för produkter baserade på mjölken från dessa arter. Mjölkens näringsvärde varierar stort mellan arterna. Protein- och fettinnehållet har en stor inverkan på vilka produkter som är möjliga att tillverka samt vilka tillverkningsmetoder som är mest lämpliga. Mjölkens innehåll av olika mikroorganismer anses vara viktigt både när det kommer till tillverkning av olika produkter samt livsmedelssäkerhet.

Nyckelord: Mjölk från mindre vanliga arter, hästmjölk, stomjölk, åsnemjölk, kronhjortmjölk, kamelmjölk, renmjölk, älgmjölk, mjölkprodukter

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Abbreviations

CMA	Cow Milk Allergy
LF	Lactoferrin
MTG	Microbial Transglutaminase
POP	Persistent Organic Pollutants
SCC	Somatic Cell Count
TBC	Total Bacterial Count

1. Introduction

1.1. Introduction to different minor dairy species

Milk and dairy products play an important part of the diet and culinary culture all over the world. The Bible phrase “land of milk and honey” has become an expression for a place of comfort and wealth (Merriam-Webster, 2021). Milk and dairy products stand for around 4 % of the dietary energy intake in developed countries and around 4 % in the developing countries (Muehlhoff et al. 2013). The milk used for human consumption and for dairy products mainly come from the four major dairy species, bovine/cow, buffalo, sheep and goat. These species contribute to 99 % of the worldwide milk production (Faccia et al. 2020). All mammals produce milk and with over 6000 species there is no surprise that there are also other dairy animals, so called minor dairy species. These come in a wide range of mammals from the clade ungulate like equines, deer’s, and camels. Minor milk species often play or have played an important role in isolated areas like desert, tundra and mountain regions, mainly in developing countries (ibid). There are also some cases where scientists and/or companies “create” new dairy species. Scientific and commercial interest in minor dairy species and their milk has increased in the last decades (Bernard Faye 2014; Faccia et al. 2020).

1.1.1. Equine

Equines are mammals from the *equine* family, consisting of horses and similar animals. Horse (*Equus ferus*) and donkey (*Equus asinus)* are domesticated members of the family (Tikkanen 2021). The horse was domesticated in Central Asia circa 3500 B.C. and archaeological evidence suggests that mare milk (horse milk) was extracted and consumed around the same time (Outram et al. 2009). Archaeological and genetic evidence suggests that the donkey was domesticated in North East Africa from wild ass circa 3000 BC (Beja-Pereira et al. 2004). Horses are mainly present in central Asia and America, while donkeys are mainly widespread in Africa, Asia and Southern Europe (Faccia et al. 2020), where they are used for transportation, recreation and meat. Nowadays, equine milk consumption is minuscule (Muehlhoff et al. 2013). Still, approximately 30 million people are estimated to drink mare milk, mainly in Central Asia and the former Soviet Union. There are no data on donkey milk consumption, but production and consumption is mainly centred in Southern Europe (Faccia et al. 2020). Milk yield~~s~~ have been estimated to approximately 2.5-3 kg milk per 100 kg body weight. Heavy horse breads produce between 5-13 kg a day. Breed, lactation stage and milking techniques have are factors that have beenindicated to affect the yield (Salimei & Fantuz 2012). One old and significant dairy mare product is koumiss, an alcohol and lactic acid fermented mare milk, which today is considered the national drink of Mongolia (Muehlhoff et al. 2013)

1.1.2. Camel

The camel has for thousands of years played an important part for people living in harsh environments such as deserts and mountainous regions. There are two species of camel, the dromedary (*Camelus dromedarius*) and Bactrian camel (*Camelus bactrianus*). Both have been domesticated and produce milk for human consumption (Muehlhoff et al. 2013). The dromedary is the more numerous of the two, it originates from Arabia and is also common in the Middle East, North and East Africa and Australia (Faye 2014). The Bactrian camel, also known as two-humped camel, is mainly present in Central Asia from where it originates (Muehlhoff et al. 2013). Camel is quantitatively the largest of the minor dairy species, contributing to approximately 0.3 % of the worlds milk production. In Sub-Saharan Africa, camel is the third largest milk specie~~s~~ after bovine and goat, contributing with ca 7 % of the milk. (Muehlhoff et al. 2013). The average milk yield is between 3-19 kg/day but yields up to 20-35 kg/day has been recorded (Al haj & Al Kanhal 2010). In contrast, a high-producing dairy cow can yield 60 kg/day (Vandelhaar & St-Pierre 2006). The use of camel milk is associated with nomad or rural life, often in isolated regions with harsh environments. Camel milk has traditionally been used for household needs. Increased demand for camel milk in urban areas has led to the commercialisation of camel milk in countries like the United Arab Emirates (Faye 2014). The dominance of dromedary led to more detailed research connected to dromedary milk and therefore this thesis will focus on this camel species.

1.1.3. Red deer

The red deer (*Cervus elaphus*) is native to western Europe (*Cervus elaphus*) and has for a long time been popular to hunt. Red deer is also farmed in a semi-domesticated manner, an industry where New Zeeland is the world leader (Shadbolt et al. 2008). Red deer has mainly been hunted and/or farmed for its meat and hide, while its milk has not been used for human consumption (Berruga et al. 2021). According to legend, the catholic Saint Gilles lived with a deer and sustained himself on her milk. Recently, there has been efforts to commercialize deer milk and research about for example the milk's components and production qualities has been conducted. These efforts are mainly centred in New Zeeland (Galloway 2019; Wang et al. 2020).

1.1.4. Reindeer

Reindeer (*Rangifer tarandus*) is an example of a milk species which used to be milked for human consumption. However, this practise has today disappeared (Gjøstein et al. 2004a). The reindeer lives in the northern parts of Scandinavia, Finland, Siberia, and Northern America (Mattioli et al. 2015). The Sami people of Northern Scandinavia and Finland have a long tradition of reindeer herding. The Sami used to milk reindeers and the milk was used for products like cheese. However, this practise faded away during the early 20th century (Gjøstein et al. 2004a).

1.1.5. Moose

The moose (*Alces alces*) lives in the forests of Northern Europe, Northern America and Siberia and is called *the King of the Forest in Sweden*. There are some moose farms, but the level of domestication is extremely low (Faccia et al. 2020). However, some dairy products made of moose milk are available on the market. One example is a small assortment of moose cheeses like moose feta, produced on a moose farm in Northern Sweden (Älgens Hus 2021).

1.1.6. Other minor milk species

There are several other minor milk species present in the world which will not be mentioned in the results and discussion sections. The yak (*Bos grunniens*) is a bovine mainly reared in the Qinghai-Tibet region (Faccia et al. 2020). The yak has traditionally played an important role as the only source of milk for nomads in isolated mountain regions of East and Central Asia (Muehlhoff et al. 2013). Llama (*Lama glama*) and alpaca (*Vicugna pasos*) are two domesticated *Cameloid* species originating from the Andeans, South America. Consumption of their milk and production of cheese is low but occurs in isolated mountain communities (Fantuz et al. 2016).

1.1.7. Aim and questionary

The aim of this study is to write a literary review which examines minor milk species with regard~~s~~ to nutritional content, products and processing, potential development of new products, microbial aspects~~,~~ and food safety. Furthermore, the study aims to answer the following questions:

1. What are the nutritional and physiochemical qualities of milk from different minor dairy species?
2. What is the current state of research and knowledge concerning the different minor dairy species and their milk?
3. What products are made from the different types of milk? Are there any potential novel products and how viable would they be?
4. What are the microbial properties of the milk from different minor dairy species? How does the microbial quality relate to production and food safety?

1.2. Method

The study was conducted in the form of a literary review. Articles from scientifically reviewed journals, both of experimental studies and literary reviews concerning relevant topics, were used. The databases Scopus, PubMed, ResearchGate and the search engines Google Scholar and SLUs primo were used. Websites of governments and authorities were used to find relevant legislation, recommendations and guidelines. Websites associated to the manufacturers' and/or sellers' products based on milk from minor dairy species, were used to get a better view of the markets for milk and milk products from minor dairy species. News articles and videos were also used, especially for information about products that are not mentioned to any greater extent in scientific literature. Some of the searching keywords were: "Minor Dairy Species", "Equine milk"," Koumiss", "Mare milk", "Horse milk", "Donkey milk", "Deer milk", "Camel milk", "Moose milk" and "Reindeer milk".

2. Results

2.1. Nutritional value of minor dairy species milk

2.1.1. Nutritional value of equine milk

Equine milk is often said to be more like human milk in composition than bovine milk (Krešimir Kuterovac et al. 2011). While this is generally true, especially when it comes to total protein and lactose levels, it is not true for all nutritional aspects. There are differences between mare and donkey milk, but overall, they are not considered significant (Muehlhoff et al. 2013). Equine milk has a low dry matter fraction, with donkey milk having the lowest content among these species. Equine milk has lower fat content compared to human and bovine milk (Table 1). Mare milk has approximately thrice as much fat (1.4 %) as donkey milk (0.4 %) (Fantuz et al. 2016). The fat of equine milk consists to 80-85 % of triglycerides compared to bovine and human milk with 97-98 % triglycerides (Barreto et al. 2019). Equine milk contains significant fractions of free fatty acids (9.5 %) and phospholipids (5-10 %), as opposed to bovine and human milk with approx. 1.5 % phospholipids and trace amounts of free fatty acids (Malacarne et al. 2002; Barreto et al. 2019). The size of the fat globule is approx. 2.5 µm for mare and 1.9 µm for donkey milk. This is small compared to bovine (approx. 3.9 µm) and human milk (ca 4.0 µm) (Faccia et al. 2020). Equine milk has low levels of of κ-casein (<1 %) and α_{s2}-casein (1-2 %) and the casein micelles are larger compared to both human and bovine milk (Faccia et al. 2020). Around 40 % of the total protein consist of whey protein, a higher proportion than in bovine (18.5 %) but lower than in human (53.5 %) milk (Fantuz et al. 2016). α- and β-lactoglobulin are the main whey proteins in equine milk, constituting approx. 28.5 % and 30.7 %, respectively, of the total whey protein content in mare milk. The whey protein lysozyme is present in high concentrations (6.59 % of whey protein content) compared to bovine milk, which only contains traces (Barreto et al. 2019).

2.1.2. Nutritional value of camel milk

The chemical composition of camel milk largely resembles that of bovine milk, with similar proportions of dry matter, total protein, fat and lactose contents. The composition and distribution of different types of proteins and fatty acids are, however, different from bovine milk (Berhe et al. 2017). The proportion of short chain fatty acids (C4-C14) is 14.6 %, to be compared with bovine milk, where the level is 25.2 %. The higher proportion of long chain fatty acids is mainly due to higher quantities of palmitoleic acid (10.1 % in camel vs 1.7 % in bovine) (Berhe et al. 2017). The fat globules are approx. 3.0 µm, larger than bovine milk (approx. 3.9 µm) (Faccia et al. 2020). The levels of β-casein (65 % of casein content) are higher than in bovine (36 %) but equal to human milk (65 %). The amount of κ-casein (3 % of casein content) is relatively low (ibid).

2.1.3. Nutritional value of milk from red deer, reindeer, and moose

Milk from deer dairy species (red deer, reindeer and moose) generally has a high content of solids. The protein and fat contents are high compared to bovine milk (Wang et al. 2017). Reindeer milk has the highest dry matter content of all dairy species. The energy content of reindeer and moose milk is higher compared to most other dairy species (Fantuz et al. 2016). Total protein content is around three times higher than in bovine milk in all three dairy deer species (Table 1) (Wang et al. 2017). Total fat content in milk from the different deer species is approximately two to five times higher than in bovine milk (Table 1) (Muehlhoff et al. 2013; Wang et al. 2017).

Several values, like whey protein content in reindeer and moose milk and total dry matter content in deer milk, could not be found in the literature (Table 1).

Table 1 Average gross composition of milk from bovine, mare, donkey, human, camel, red deer, reindeer, and moose. Adapted from Muehlhoff et al. 2013, Fantuz et al. (2016), Wang et al. (2016), Faccia et al. (2020) and Serrano et al. (2020)

	Bovine	Mare	Donkey	Human	Camel[1]	Red deer[2]	Reindeer	Moose
Dry matter (g)	12.7	10.2	8.8	12.4	12.5	NA	32.1	23.2
Energy (kcal)	62	48	37	70	56	158.2	196	129
Total protein (g)	3.4	2.1	1.7	0.9	3.3	8.8	10.4	10.5
Casein content (g)	2.62	1.07	0.78	0.37	2.65	8.7	8.3	NA
Whey protein (g)	0.63	0.83	0.65	0.76	0.81	0.6	NA	NA
Total fat (g)	3.7	1.2	0.4	3.8	3.8	7.0-19.7	16.1	8.6
Lactose (g)	4.8	6.4	6.9	7.0	4.5	2.6-6.2	2.9	2.6

Footnotes Table 1: [1]Dromedary camel. [2]An average could not be found for all nutritional components of red deer milk and therefore a range is indicated. NA: Not analysed

2.2. Equine milk

2.2.1. The equine milk product koumiss

The main processed mare milk product is the fermented alcoholic drink koumiss, also known as kymis and airag in Mongolia. The fermentation process results in 2% alcohol and 0.5-1.5 % lactic acid (Danova et al. 2005). The taste is described as mainly sour/acidic with a slight sweetness. Descriptions of colour vary from ivory to bluish-white to slightly yellow (Muehlhoff et al. 2013; Faccia et al. 2020; Tang et al. 2020). The acidity, caused by the fermentation, gives a weak coagulum which contributes to a yoghurt like texture (Muehlhoff et al. 2013). Playing an important role in Mongolian culture, koumiss is consumed at Lunar moon year, weddings and other rituals and celebrations and is considered the national drink (Bat-Oyun et al. 2015). Besides lactic acid, other organic acids have also been identified, mainly acetic, tartaric, and malic acid. The approximate total acid content is 6.54 g/L (Tang et al. 2020). The fermentation process barely affects protein and fat levels but decreases lactose levels from circa 6.4 % to circa 2 % giving a conversion rate of ca 67 %. (Danova et al. 2005). There are different types of koumiss; "strong", "moderate and "light". "Strong" koumiss has the highest conversion rate of lactose to lactic acid (the proportional amount of lactose that is fermented into lactic acid) and therefore the highest lactic acid concentration and the lowest pH (Table 2). "Light" koumiss has the lowest lactic acid concentration and the highest pH at 4.5-5, whereas "moderate" has values between "strong" and "light" (Table 2) (Danova et al. 2005). There is also a distilled version in Mongolia called arkhi, containing up to 10-15 % alcohol. Koumiss has been seen as a therapeutic product and has often been consumed for its believed health benefits. (Faccia et al. 2020).

Production of koumiss has to a large extent been industrialized. Industrialized production often uses modified bovine milk due to scarcity of mare milk. Lactose addition and removal of fat are some methods of modification to make the bovine milk more like the equine counterpart. However, traditional production of koumiss is still common in Mongolia (Danova et al. 2005; Bat-Oyun et al. 2015; Faccia et al. 2020). Pre-made starters are used at industrial level. Examples of bacteria used in the starters are *Lactobacillus bulgaricus* in "strong" koumiss and *Lactobacillus fermentum* in "moderate" (Table 2). "Light" koumiss uses *Streptococcus* bacteria like *Streptococcus thermophilus* rather than *Lactobacillus* bacteria (Table 2) (Danova et al. 2005; Tang et al. 2020). Traditional koumiss production uses back slopping to initiate fermentation (Danova et al. 2005). Yeasts are important microorganisms in koumiss production as they are responsible for producing the alcohol. Yeasts used are mainly from the genus's *Kluyveromyces, Candida* and *Saccharomyces* (Danova et al. 2005). Several studies focusing on microbes and content of koumiss have been conducted. Most of the identified lactic acid bacteria have been homofermentative but some, e.g. *L. raffinolactis* and *L. lactis*, have been linked to acetic acid production (Danova et al. 2005; Tang et al. 2020). A study made by Danova et al. (2005) found that the different microbes present in koumiss vary significantly in their conversion rates of lactose to lactic acid and in their carbohydrate fermentation patterns.

Koumiss-like products are also made from donkey milk (Faccia et.al. 2020).

Table 2 Chemical properties and types of bacteria in different types of koumiss. Data adapted from Danova et al. (2005) and Tang et al. (2020)

Type of koumiss	*Conversion rate of lactose to lactic acid (average)*	*Lactic acid (%)*	*pH-range*	*Bacteria used in fermentation*
Strong	90 %	0.91-1.08	3.3-3.6	*Lactobacillus bulgaricus, L. rhamnosus*
Moderate	50 %	0.73-0.90	3.9-4.5	*L. acidophilus, L. plantarum, L. casei, L. fermentum*
Light	NA	0.54-0.72	4.5-5.0	*Streptococcus thermophilus, Str. cremoris*

2.2.2. The potential equine milk product - cheese

Equine milk is generally difficult to coagulate. The low level of κ casein is often believed to be an important factor in insufficient coagulation. High proportions of whey protein and relatively low proportions of protein and fat (Table 1) are also believed to explain the inadequate coagulation (Faccia et al. 2018; D'Alessandro et al. 2019). Bovine rennet, consisting of chymosin and pepsin, initiate none to little coagulation in unmodified equine milk (Faccia et al. 2020). In the last years, several scientists have been able to produce donkey milk cheese with different methods (Faccia et al. 2020). Faccia et al. (2018) tried to coagulate donkey milk, both pure and mixed with goat milk, with calf rennet, to create cheese. The authors modified the pH and Ca^{2+} concentrations and produced fresh cheese. However, Faccia et al. (2018) noted that so called "extreme technological conditions" were needed to achieve a curd firm enough. The texture was fragile and slightly soluble, and the taste varied from sweet to acid depending on the amount of goat milk. The pure donkey milk gave a 5.9 % cheese yield which can be compared to approximately 10 % cheese yield for bovine milk. (Walstra 2006; Faccia et al. 2018). Alessandro et al. (2019) also managed to coagulate donkey milk and turn it into cheese with microbial transglutaminase (MTG), using a method similar to Faccia et al. (2018). MTG was shown to affect the viscosity, overall gel formation and colour. In this case, the cheese yield varied between 6.91 to 7.39 %. Lanelle (2015a) successfully used camel chymosin in combination with donkey milk resulting in a cheese yield of 3.32 %. A long coagulation time of approximately five hours was reported (Lanella, 2015a). Camel chymosin was also used to produce mare milk cheese with a yield of 4 % (Lanelle 2015b). All these studies used a starter culture consisting of *Streptococcus thermophilus*. Lanella (2015a) also used *Lactobacillus delbrueckii* ssp. *bulgaricus*. All the studies mentioned above produced fresh cheeses. Studies describing manufacture of semi-hard or hard cheese could not be found.

One farm in Serbia commercially produces donkey cheese based on a mixture with goat milk. It has been described as the world´s most expensive cheese, with a price of 1000 euros per kilogram, where one kilogram of cheese requires 25 litres of donkey milk (Varricchio & Morgan 2021).

2.2.3. Equine milk as a potential baby formula

The fact that equine milk is more similar to human milk than bovine milk, has evoked an interest for equine milk as a possible raw material for production of infant formula directed to children with cow milk allergy. Infant formula made from bovine or goat milk is currently produced by lowering the protein content and adding certain carbohydrates and fatty acids to resemble human breast milk (Kårén 2020). Whey protein is believed to be more easily digested, therefore it is often the basis for baby formula (NHS 2019). Cow milk allergy (CMA) is an allergy towards one or several proteins in cow milk and is present among 2-3 % of children under three years (Fantuz et al. 2016). CMA mostly disappears with age and young children are recommended to eat a non-dairy diet (Kårén 2020). CMA poses a problem for young children fed on infant formula and therefore, a hypoallergenic formula is used, a bovine milk-based formula with complete protein hydrolysation. Children with CMA allergy cannot consume goat milk-based formula due to the similarity between milk proteins of bovine and goat origin (NHS 2019) and therefore the equine milk substitute could be of interest.

Some smaller studies have been conducted testing the effect of mare and donkey milk on children with CMA. In a study by Businco et al. (2000), 25 children with CMA, between 1.5-6 years, did a skin prick test with mare's milk. In the test, 96 % of the children showed negative results when exposed to the mare milk while all showed positive results for cow milk (Businco et al. 2000).

In another study by Vita et al. (2007), 28 children between 0.5-3 years old were given donkey or goat milk for six months, followed by the other type of milk for three months. In the study, 88 % of the children showed no negative symptoms to donkey milk, while 88 % of children displayed negative symptoms for goat milk (Vita et al. 2007).

2.2.4. Hygienic quality of equine milk

Few studies have investigated the somatic cell count (SCC) in equine milk, but the available data suggests that SCC are generally lower in equine than bovine milk (Faccia et al. 2020). The low risk for mastitis due to the small udder having limited exposure for infection, is believed to be one reason for the low SCC (Uniacke-Lowe et al. 2010). The relatively high lysozyme content (approx. 6.59 %) is also believed to give equine milk a high antimicrobial activity, which may contribute to the relatively low SCC (Faccia et al. 2020).

2.3. Camel milk

2.3.1. Camel milk products

Camel milk has mainly been consumed fresh or as spontaneously fermented products (Muehlhoff et al. 2013). Ghee, a type of dehydrated butter, is made from camel milk in the middle east (ibid).

There are several traditional and widely consumed spontaneously fermented camel milk products. Gariss is a sour and alcoholic fermented product common in Somalia and Sudan (Shori 2012). Susacc is a prevalent part of the diet in several East African countries, characterised by a smoky and astringent taste (Jans et al. 2012; Shori 2012). Shubat is a fermented camel milk drink in Turkey and Central Asia characterised by its sourness and high CO_2-content. (Shori 2012). Traditionally, natural spontaneous fermentation or back slopping without heat treatment has been used and is still the commonly used procedure (Shori 2012). The use of starter cultures is seemingly small and is often stated as a potential for product development (Shori 2012; Berhe et al. 2017; Faccia et al. 2020). Fugl et al. (2017) isolated several bacteria from fermented camel milk, like *Lactococcus lactis*, *Pediococcus acidilactici* and *Lactobacillus plantarum* which they deemed to have potential use in starter cultures.

A wide range of products like ghee, coffee with camel milk, powdered milk, flavoured milk, and camel ice cream is sold in the United Arab Emirates (Camelicios 2021). Camel ice cream is also made and sold by Bedouins in the Israeli tourist sector (Muehlhoff et al. 2013). A small market is present in Europe, there is a Dutch company that sells for example unpasteurized milk, skin care products, bread and chocolate made from camel milk (Oasis Milk 2021). The milk companies generally emphasise camel milk as a “healthy” product in their marketing (Camelicious 2021; Oasis milk 2021).

2.3.2. Potential camel milk products

Coagulation of camel milk is difficult to achieve, with generally slow coagulation, low yield and weak curd (Shori 2012). It is theorised that the low levels of κ-casein and relatively high proportions of whey proteins might be the reason for the poor gel quality. This in turn makes it difficult to manufacture products like yoghurt and cheese (Berhe et al. 2017; Mohamed et al. 2020).

Laboratory attempts to make yoghurt from camel milk have been carried out with variying degrees of success. The limited coagulation of camel milk causes the curd to become fragile and the final yoghurt texture to be perceived as too thin (Berhe et al. 2017). In a study by Hashim et.al. (2009), different types of yoghurt from camel milk were made and tested on a consumer panel where the camel yoghurts were compared with bovine milk yoghurt. Sensory attributes that were evaluated were firmness, smoothness, flavour, body and sourness. Standard yoghurt culture and stabilizers were used in all yoghurts and yoghurt that also contained gelatine or alginate, respectively, and Ca^{2+} were made. The camel yoghurt was thin and soft in texture and generally gained a low score by the panel compared to bovine yoghurt. Gelatine or alginate treatment improved the score from the panels, but even here the scores were lower than for bovine yoghurt (ibid).

Camel milk has higher proportions of long chain fatty acids than bovine milk which is believed to give a higher melting point of camel milk fat (Berhe et al. 2017). Due to the higher melting point, higher temperatures are required when churning camel butter compared to bovine butter. A temperature of 22 ˚C has been proven to be effective for churning of camel butter compared to 13-14 ˚C for bovine butter (ibid).

2.3.3. Microbial content and antimicrobial properties of camel milk

Camel milk is often consumed raw/unpasteurized (Muehlhoff et al. 2013), and many of the traditional fermented products are made from raw milk (Jans et al. 2012). Unpasteurized milk is generally considered as unsafe food, although some manufacturers describe it as more natural and healthier. This has made unpasteurized products quite popular in alternative food markets (Livsmedelsverket 2020). Studies have shown that the chemical composition of camel milk does not change by pasteurization, which is true for the milk from all milk species (Shori 2012).

The microflora of camel milk is typical for milk in general with several *Lactobacillus* spp. and *Streptococcus thermophilus*. The pathogens *Streptococcus agalactiae* and *Staphylococcus aureus* have also been found in the raw milk of camels (Jans et al. 2012). The microbial content of unpasteurized fermented camel milk was analysed by Fugl et al. (2017). They found significant amounts of bacteria from bacteria families that contain pathogens, e.g. *Escherichia*. The bacteria species *Streptococcus infantarius,* which has strains that can be used in food fermentation but also strains that are pathogenic, was also identified. (Fugl et al. 2017).

Camel milk has been shown to have some inhibitory effect towards several bacterial species like *Escherichia coli, Listeria monocytogenes* and *Staphylococcus aureus* (Benkerroum et al. 2004; Al haj & Al Kanhal 2010). Heat treatment was shown to decrease camel milk inhibitory effect on bacteria in a study by Benkerroum et al. (2014).

2.4. Red deer milk

2.4.1. Red deer milk products

The state-owned New Zeeland agricultural company Pāmu started to produce and sell red deer milk in 2019. The milk is turned into milk powder and sold to gourmet restaurants (Galloway 2019). There are reports of several products like yoghurt and Crème brûlée based on red deer milk (Pāmu 2021). The New Zeeland Company Talbot Forrest Cheese is selling Havarti and Gouda like cheeses made from the deer milk (Talbot Forest Cheese 2021).

The estimated pH range of deer milk is unclear and ranges of 6.2-7.1 and 6.65-6.71 have been observed. The values are similar, especially the latter, to pH in the major milk species (Berruga et al. 2021).

2.4.2. Red deer milk protein and gels

Proteins of deer milk have shown different properties than protein in milk from other species. Both whey and casein proteins in deer milk have shown to migrate differently on SDS-page gels and 1D-page separation than proteins in milk from other species. Deer caseins have higher mobility on SDS-page than the caseins from other species, whereas the whey proteins α-lactalbumin and β-lactoglobulin have shown lower mobility on SDS-page compared to the corresponding proteins in milk from species like bovine or goat (Roy et al. 2020). Overall, different migration of deer milk proteins has been reported on both SDS-page and starch gel electrophoreses, indicating that these proteins have notably different composition, structure, and properties (Ha et al. 2014; Roy et al. 2020).

In a study made by Roy et al. (2020), skim milk gel from red deer, bovine, sheep, goat and buffalo was created and their properties were compared. Gels were formed with glucono-δ-lactone alone and in a combination of glucono-δ-lactone and porcine pepsin. The protein networks that formed during gelation were visualised with laser- and electron microscopy. The deer skim milk gels were the most dense and compact and with fewer pores (Roy et al. 2020). The physiochemical properties of the skim milk from the different specieses were measured as well. Deer skim milk had the highest dry matter content and highest content of all measured components (fat, protein, ash, calcium, and phosphorus) except for carbohydrates. The fat content of approx. 0.27 % in red deer skim milk can be compared to the the legal maximum fat content in bovine skim milk which in New Zeeland is 0.15 %. (Roy et al. 2020; Foodstandards 2021).

2.4.3. Hygenic quality of red deer milk

Few studies have been made regarding SCC in deer milk and conflicting results have been observed. A study done by Serrano et al. (2020) reports a small increase at the end of lactation while another by Berruga et al. (2021) did not observe any significant increase. The total bacterial count (TBC) was also measured and showed no clear pattern of increase or decrease in levels during the lactation. The mean TBC in the milk slightly exceeded EUs legal limit for raw bovine milk, but was below the limit for small ruminants (Berruga et al. 2021).

The antimicrobial properties of the whey protein lactoferrin (Lf) and its hydrolysates, were tested and compared to those of Lf in bovine milk in a study by Wang et al. (2020). The results indicated that deer Lf slowed down growth of the pathogens *Escherichia coli* ATCC 25922, and *Staphylococcus aureus.* Bovine Lf showed a stronger antimicrobial effect than that of red deer Lf. Gastric and duodenal digestion produced Lf hydrolysates, the red deer Lf hydrolysates was indicated to have stronger bactericidal effect than bovine Lf hydrolysates against *E. coli*.

2.5. Reindeer milk

The records related to reindeer milking in the past, show that the production and use of this milk was quite sophisticated and developed. Naphí was a milking tool in which the milk was collected during milking. The Naphí was designed to enable a steady one hand grip and for milk to not slip out. Naphís are still made as Sami handicrafts. The milking was conducted during summer and autumn, the reindeer was milked every other day and yielded a couple of decilitres of milk per day (Pohjanen 2009). Some research on reindeer husbandry and even the nutritional composition of the milk and cheese were conducted in the early 1900s (Lantto 2011).

The milk was used for a wide range of products. To preserve the milk for the winter, cheeses and fermented products were made. Both drying and smoking of cheese occurred which contributed to the preservation. Freezing or drying of the milk also occurred (Pohjanen 2009). Another notable dish was a porridge made from heated reindeer milk and mashed herbs (samer.se 2021). The only reindeer product manufactured in modern times is reindeer cheese made on the farm Vardofjäll in northern Sweden (Gustavsson 2017).

The decline of reindeer milking is due to several factors. Reindeer husbandry is today more extensive with lower monitoring of the reindeer herds which makes milking difficult. The calf of reindeers that are milked risks being undernourished and therefore, the reindeer husbandry today solely focuses on meat and hides resulting in better economic benefits (Lantto 2011).

There is plenty of research concerning the milking itself. Research has shown that it is possible to milk reindeer with a milking machine. It has been found, that the reindeer hind gives an output of up to 1000 g of milk per day during lactation peak (three weeks) and has an output of 200 gram per day at the end of lactation (Gjøstein et al. 2004a; Gjøstein et al. 2004b).

The lipophilic toxins called persistent organic pollutants (POP), e.g. dioxins, have been suggested to be a potential problem with reindeer milk (Wang et al. 2017). POPs have been linked to adverse effects on for example human reproduction, immune system and development (United States Environmental Protection Agency 2009). Reindeer partly lives on potentially polluted flora and the milk has a high fat concentration (see Table 1). Reindeer milk could therefore contain quite high POP concentration. While POPs have been found in reindeer calves, description of negative effects on reindeer calfes from POPs could not be found. (Wang et al. 2017).

2.6. Moose milk

Practically all research about moose milk concern the nutritional composition. The only active producer of moose milk products is Älgens hus, a moose farm in Northern Sweden. Here, four types of cheeses, i.e. blue cheese, dried blue cheese, camembert type cheese and feta are manufactured. Notably, the producer claims that the mould culture in blue cheese grows relatively quick, probably due to the high protein content in moose milk (Table 1). The producer has also developed a recipe on a parfait made of the feta cheese (Älgens hus, 2021). It seems there has also been a Russian farm producing moose milk, where the milk was sold commercially as a therapeutic product (Wang et al. 2017). However, no research concerning potential effect on human health by moose milk consumption could be found.

3. Discussion

There is a wide variety of minor dairy species. Their milk and products have traditionally been consumed, and is to large extent still used in isolated and developing communities. Even if this consumption is miniscule on a global scale, these minor dairy species often plays the important role as one of the few or even the only source of milk, like the camel in some desert regions. There is a small commercial sector for most of the examined minor dairy species, which seems to have grown in recent years. Industrialisation and standardization also seems to have grown, as seen with modern koumiss production (Danova et al. 2005). A considerable amount of research about minor dairy species has been conducted in recent years.

There is a great variation in gross and nutritional composition between different milk species (Table 1). The content and composition of protein and fat in milk seem to have an influence on what products can be made from the different types of milk. It also seem to affect which methods that are suitable for production of different products.

There is potential in development of equine cheese, given that several possible techniques have been suggested and also shown encouraging results. The donkey cheese made in Serbia had a cheese yield of 4 % without taking the goat milk into account (Varricchio & Morgan, 2021). Both Faccia et al. (2018) and Alessandro et al. (2019) got higher yields (between 5.9-7.39 %) without using goat milk. The camel chymosin method reported by Lanelle (2015a) resulted in lower yields (3.32 %). However, camel chymosin is the only method found to have been used for production of mare milk cheese. (Lanelle 2015b).

According to Høst et al. (2004), the recommendation is that at least 90 % of children with cow milk protein allergy should tolerate any alternative baby formula, with a confidence level of 95 %. Mare milk as reported by Buscino et al. (2000), meets the acceptance criteria with 96 % tolerance, while donkey milk as reported by Vita et al. (2007) did not meet the recommendations (88 % tolerance). However, Vita et al. (2007) was more extensive with long dietary exposure as opposed to the prick test described by Buscino et al. (2000). Overall, the tests are few and with few test subjects. None of the studies involved children under six months, the age when baby formula is most extensively used, making tolerance and confidence levels unclear (Kårén 2020). Buscino et al. (2000) and Vita et al. (2007) both pointed out that the high lactose levels of equine milk could contribute to more pleasant taste than the bitter and poor taste associated with hypoallergenic formula (Høst & Halken 2004).

Of all the examined milk species, camel milk shows the highest potential. It could be considered a major milk species in Sub-Saharan Africa and is an important part in the diet for several communities (Muehlhoff et al. 2013; Bernard Faye 2014). A wide array of products, both traditional like ghee and novel ones like ice cream are already out on the market (Muehlhoff et al. 2013). One concern with camel milk is the habit of consuming this milk unpasteurized, which gives an increased risk as pathogens like *S. aureus* have been identified by e.g., Jans et al (2012). On the other hand, camel milk has shown antimicrobial activity, in many cases higher than in bovine milk as shown by Benkerroum et al. (2004). More research must be performed to investigate the occurrence and levels of different pathogens to get a sufficient picture of risks with the consumption of raw camel milk. Until then, both producers and consumers should be informed that pasteurization does not lower the quality of camel milk. However, the microflora used for fermented products would probably not survive the pasteurization. Development and usage of starters could solve this problem and has also been suggested by Fugl et al. (2017).

Milk from deer species shows potential when it comes to developing new products. Several products like moose cheese, red deer yoghurt and Crème brûlée seem to have been developed without extensive research. The high proportions of protein and fat in this milk most likely give good coagulation properties which make it relatively easy to develop new coagulated products. Ha et al. (2014) and Roy et al. (2020) pointed out that results by SDS-PAGE indicated that deer milk proteins could have quite different structure and properties compared to bovine milk proteins. More research about the proteins could help in developing new products and also in improving product quality. The producers of moose cheese, Älgens hus (2021) claimed that the high protein content of moose milk promoted rapid mould growth in their cheese. No research related to cheese made of milk from moose or other deer species could be found. Research about this could clarify if the theory of "Älgens house" is valid, and give better knowledge about the susceptibility to mould in cheeses from deer species, improving both food safety measures and development of moulded deer cheeses.

If the reindeer milk sector would be revitalised, records from the past could be used as inspiration and basis for new products. Literature studies with the goal of finding recipes and more information about old reindeer milk products would therefore be beneficial. However, as Lantto (2011) pointed out, reindeer milking was phased out for economic reasons and the viability of re-vitalisation is therefore questionable. On the other hand, techniques that were not used in the past, e.g. milking machines, are now available, which might increase viability (Gjøstein et al. 2004b). POPs in reindeer milk might be a concern. However there are no known negative effects on calfs from POPs and humans would probably consume less milk than calfs.

Even if many products, e.g. equine cheese and camel butter seem to be technically possible to produce, they are not guaranteed to be viable on the market. As Hashim et al. (2009) showed in their yoghurt study, consumers might prefer the products made from major dairy species. Consumer panels should therefore be an integrate part in research and development of novel products made with milk minor dairy species.

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