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Overview of Milk of Non-Bovine Mammals (Second Edition)

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1 Introduction

The First Edition of *Handbook of Milk of Non-Bovine Mammals*, compiled information on the availability, composition, and technology of milk produced from domestic non-bovine mammals throughout the world, has been a success, so much so that it has been translated into two additional languages, Spanish and Chinese. Therefore, a Second Edition has been recommended by Blackwell-Wiley Publishers. We welcome the addition of W.L. Wendorff to the editor team, who is an international authority on cheese technology and dairy sheep besides representing the leading US dairy state Wisconsin. We also welcome several new expert co-author contributors: Mariana Marques de Almeida from Portugal, Golfo Moatso from Greece, Samir Kalit from Croatia, Elizabetta Salimei from Italy, Ying Ma and Shenghua He from China, Leorges M. Fonseca from Brazil, Benedicte Coude from France, Mian Murtaza from Pakistan, Shane Crowley from Ireland, David Thomas, John Lucey, Mark A. Johnson, and Pat Polowsky from Wisconsin, USA.

The First Edition of *Handbook of Milk of Non-Bovine Mammals*, published in 2006, covered the eight domestic non-bovine milk-producing species: goats, sheep, buffalo, mare, camel, yak, reindeer, human, as well as sow, llama, and other minor species. This Second Edition, after reviewing and updating the First Edition has added the milk of donkeys, zebu, and mithun species. Since 2006 much new information from research with these species has become available and two significant new publications from the international Food and Agriculture Organization in Rome, Italy (Kukovics, 2016; Muehlhoff, Bennett, and McMahon, 2013), have added emphasis on the importance of non-bovine domestic species for providing people in areas of difficult climate and geological conditions with essential nutrition and sustainance. "There is huge scope for developing other dairy species … and that alpaca, donkey, moose, reindeer and yak milk should be used to counteract high cow milk prices …" in the developing world (Muehlhoff, Bennett, and McMahon, 2013) has been stated in this latest authoritative FAO publication.

Dairy goats in particular have led in increasing numbers (66% during the last 20 years worldwide versus 14% for dairy cattle), because they are profitable for poor households by valorizing low quality forage, tolerate water shortage, and enhance rangeland biodiversity (Kukovics, 2016). Non-bovine commercial dairy products mean the reality that in many parts of the world the Western ideal milk-producing cow needs help from other domestic mammals, which are

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better adapted to adverse conditions of climate and geological environmental conditions. The knowledge of their productivity and composition of their products has not been published much in the Western world and non-Western scientists working with these mammals have not been heard much in the English literature. This Handbook, however, aspires to amend this situation by focusing on these other important milk-producing domestic mammals, the value of their products, and their future potential. As the FAO book stated, “there is huge scope for developing other dairy species …” (Muehlhoff, Bennett, and McMahon, 2013).

It has also been learnt that the Nordic countries, Norway, Denmark, Sweden, Finland, Iceland, and Greenland have invested $112 million for 2015–2018 in four new interdisciplinary Centers of Excellence to improve and develop animal products more and better for human nutrition and health in those adverse arctic regions of the world in order to sustain their human populations (Nordforsk, 2005). This is in addition to a research program by the University of Alaska at Fairbanks with reindeer in cooperation with the California Polytechnic Institute (Alaska, 2014).

As consumers in modern societies are seeking for diversified, sophisticated, and nutritious foods, more and more people in developing and developed countries have an interest in knowing about the composition and constituents in dairy products as they relate to human health (Campbell and Marshall, 1975; Smith, 1985; Park and Haenlein, 2006). Not many people paid much attention or knew much about good and bad types of fat and fatty acids until recently. Today’s nutrition labels on food products indicate levels not only of protein, fat, carbohydrates, sodium, calcium, and vitamins but also of such special ingredients as saturated, unsaturated, omega-3, conjugated, and trans-fatty acids. This open knowledge leads to interest into which dairy products may be superior to others and which animal feeding system, such as pasturing versus barn feeding, or which animal species produces a more suitable or preferable human food to others. In terms of milk for infants or sick patients, they need to know which milk is closest to human milk and best for babies, which milk creates less allergies, which one is better tolerated by people with gastrointestinal ailments, which dairy product causes no lactose intolerance symptoms, or which species of milk and dairy products have better digestibility (Park and Haenlein, 2006).

2 Evolution of the Bovine and Non-bovine Dairy Industry

Throughout history, in search of socioeconomically feasible and nutritionally superior sources of food, man has domesticated some milk-producing dairy species, and selected and bred them to produce large volumes of milk in excess of the necessary amounts needed to nourish the animal’s own offspring. This surplus production of milk beyond nourishing the young has become the foundation of the modern dairy industry. In North America, Europe, Australia, and New Zealand, the dairy industry is one of the most integral enterprises and important national economies among all agricultural production businesses (Park and Haenlein, 2006).

Even though the dairy cow has been the predominant domesticated animal species for dairy production in developed countries, the goat, sheep, water buffalo, yak, camel, mare, reindeer, as well as some other minor mammalian species have been domesticated, kept, and bred for milk production in regions of the world where the difficult environment required special adaptation, and for which many of the non-bovine mammals are better suited (Park and Haenlein, 2006).

The knowledge on anatomy, histology, physiology, and biochemistry of milk component synthesis and their secretory processes in the mammary gland is essential for the efficient production, maintenance, and utilization of milk for human consumption. Greater understanding of this will provide dairy producers with the integral and necessary capacity to improve management and environmental conditions of their dairy animals for higher efficiency, greater quality, and larger volumes of milk production. Such knowledge would also give dairy producers opportunities for affecting the composition of milk to meet more functionally the nutrition and health needs of people (Park and Haenlein, 2006).

Milk is one of the most nutritious natural foods and has been a basic component of the human diet since early history. Milk drawn from the lacteal glands is highly perishable and is adversely affected by improper practices of feeding and handling of the animals, handling of milk during and after milking, cooling, transportation, pasteurization, processing, packaging, processing equipment, and storage (Le Jaouen, 1987; Peters, 1990; Park, 2010). Through understanding of the basic science of lactation in domesticated mammals, the milk production volume and quality can be maximized for effective utilization and processing of milk products for human consumption.

Western animal science has demonstrated and developed tremendous genetic resources in dairy cows; where 50 years ago they produced about 12 kg of milk per day today many have evolved through genetic selection to produce 50 kg of milk per day. Likewise Western dairy sheep and dairy goats have evolved from producing 1 kg of milk per day to as much as 10 kg of milk per day during the last 50 years (Haenlein, 2007). This is the challenge to the developing world dairy science to which this Handbook wants to help catch up with the most up-to-date knowledge and to recognize scientists in the developing world. Overall there are three major challenges facing progress in non-bovine dairying:

1) The size and metabolic activity of the mammary gland must increase through genetic selection, especially in mares, donkeys, camels, and reindeer.
2) The size of the teats and their placement on the udder must become more practical for manual and machine milking procedures, especially in dairy sheep.
3) The milk let-down reflex via the oxytocin hormone release must become habituated to the human presence and their stimulation without the need to have a calf or foal present.

3 Composition and Secretion of Milk of Minor Species

The milk composition data of at least 194 mammalian species have been identified in a comprehensive review (Oftedal, 1984), while relatively few studies on non-domestic species were found to be careful and reliable. Only 55 species including domesticated mammals had systematic data for all lactation stages. It was shown that much of the available information, especially on wild species, was from opportunistic situations, in which the effects of stage of lactation, compromised maternal or infant health, and sampling bias could not be tested (Oftedal and Iverson, 1995).

The constituents of milk are produced by the epithelial cells of alveoli in two ways: synthesis and diffusion. Diffusion is carried out directly from blood (Park *et al.*, 2013). Even if the osmotic pressure is the same for milk and blood, markedly different compositions exist between the two physiological body fluids. Milk proteins are mainly caseins, at least in ruminants, while the principal proteins in blood plasma are albumins and globulins. In addition, milk contains more sugar (lactose), fat (lipids), calcium, phosphorus, and potassium, but often less protein, sodium, and chlorine than blood (Swenson, 1975; Park and Haenlein, 2006).

Lactose and casein are two characteristic components of milk, besides fat, minerals, and vitamins. Even though the composition of milk is influenced by genetic, nutritional, and environmental factors, the amounts of the major and minor constituents in milk vary genetically substantially between species. Many of the rapidly growing species, such as the rabbit and rat, have high protein contents in their milk, but the correlated relationships between rates of reaching maturity and levels of protein in milk are not consistently linear. In general, milk of marine mammals such as dolphins, seals, whales, and polar bears contain a high fat content

(Swenson, 1975; Park and Haenlein, 2006). The most constant component in milk is lactose, which is found between 3 and 7% in mid-lactation milk of different species. Among marsupials, a class just below mammals but also providing milk to their young inside their pouch, the kangaroo milk contains pentoses instead of lactose, as well as proteins and other nitrogenous compounds, which are not usually associated with mammalian milk (Bolliger and Pascoe, 1953; Park and Haenlein, 2006).

A summary of comparative milk composition of domesticated and some wild mammals is presented in Table 1.1. These values are average figures and can be used only for general comparisons between species. Many data in the table, especially for non-domesticated species, are based on few analyses and have little information about the stage of lactation, when the milk samples were taken. There can even be significant differences in the composition of milk between different glands of the same animal, and substantial variations do occur diurnally and from day to day (Park and Haenlein, 2006).

The onset of copious milk secretion (lactogenesis) occurs concomitantly with parturition in most mammalian species. Lactogenesis takes place in two stages: the first prepares the mammary glands for milk secretion and this usually occurs some time in later pregnancy. The second stage is the onset of milk secretion at the time of parturition (Hartmann, 1973; Fleet *et al.*, 1975; Park *et al.*, 2013).

In the cow, lactogenesis coincides with parturition (Peaker and Linzell, 1975). In the rat, milk is secreted into the mammary ducts 4 hours prior to parturition (Kuhn, 1977). On the other hand, lactogenesis is delayed for 48 or 72 hours post-partum in humans and guinea pigs, which may be attributable to the slow post-partum decrease in progesterone levels in the two species (Neville, 1983).

Milk ejection occurs at the teats of the mammary glands by the stimulation of the suckling young or by the milking machine via a series of physiological and hormonal reflex mechanisms. Hormones have definite influences on the initiation of the milk secretion process (Schmidt, 1971; Park *et al.*, 2013). The continued secretion, the amount of milk produced, and the composition of milk is controlled by several hormonal and nutritional factors within the animal. In dairy cows and goats, somatotrophin and thyroxine increase the level of milk production (Schmidt, 1971; Swenson, 1975), which has to be removed periodically in order to have continued secretion of milk. However, secretion of milk, that is, its removal, from the mammary gland usually requires the stimulation of the nervous system through the young's suckling or manual pre-milking procedures. If the milk is not evacuated from the glands, the secretory process declines and secretion stops with a complete involution of the secretory tissues. Milk secretion proceeds by a physiological feedback system. The nervous stimulus induces the release through the blood stream of the hormone oxytocin from the pituitary gland in the brain, which causes the myoepithelial cells surrounding the milk-producing alveoli to contract, thus forcing the milk from the alveoli into the udder ducts and cisterns (Schmidt, 1971; Park *et al.*, 2013).

4 Features of this Second Edition of *Handbook of Milk of Non-Bovine Mammals*

Due to the paucity and severe shortages of technical and scientific literature in the field of milk and dairy products of non-bovine dairy species, the publication of the First Edition of *Handbook of Milk of Non-Bovine Mammals* was a great success. The worldwide reception of the First Edition by the readers and scientific audience and the demands of updating new research data and reports in the field for the past decade have necessitated the publication of this Second Edition.

Table 1.1 Gross composition (%) of milk from domesticated and some wild mammals.

Species	Fat	Protein	Lactose	Ash	Total solids	Reference
Antelope						
Impala	20.4	10.8	2.4	1.3	34.9	Ben Shaul, 1962
Pronghorn	13.0	6.9	4.0	1.3	25.2	Einarsen, 1948
Ass (donkey)	1.2	1.8	6.5	0.5	10.0	Salimei and Fantuz, 2013
Baboon	5.0	1.6	7.3	0.3	14.2	Buss, 1968
Bear						
Grizzly	3.0	3.8	4.0	1.3	12.1	Ben Shaul, 1962
Polar	31.0	10.2	0.5	1.2	42.9	Baker *et al.*, 1963
Bison	1.7	4.8	5.7	0.9	13.1	Altman and Dittmer, 1961
Buffalo						
Egyptian	7.7	4.2	4.9	0.8	17.6	Pandya and Khan, 2006
Philippine	10.4	5.9	4.3	0.8	21.4	Altman and Dittmer, 1961
Camel	0.4	11.2	2.65	1.0	15.25	El-Agamy, 2006
Cat	7.1	10.1	4.2	0.5	21.9	Altman and Dittmer, 1961
Cow						
Ayrshire	4.1	3.6	4.7	0.7	13.1	Armstrong, 1959
Brown Swiss	4.0	3.6	5.0	0.7	13.3	Armstrong, 1959
Guernsey	5.0	3.8	4.9	0.7	14.4	Armstrong, 1959
Holstein	3.6	3.3	4.6	0.7	12.3	Park, 2006a
Jersey	5.5	3.9	4.9	0.7	15.0	Armstrong, 1959
Zebu	4.9	3.9	5.1	0.8	14.7	Verdiev and Veli-Zade, 1960
Chimpanzee	3.7	1.2	7.0	0.2	12.1	Ben Shaul, 1962
Coyote	10.7	9.9	3.0	0.9	24.5	Ben Shaul, 1962
Deer	19.7	10.4	2.6	1.4	34.1	Spector, 1956
Dog	8.3	9.5	3.7	1.2	20.7	Smith, 1959
Dolphin	41.5	10.9	1.1	0.7	54.2	Altman and Dittmer, 1961
Elephant	15.1	4.2	5.1	0.7	24.1	Altman and Dittmer, 1961
Fox	6.3	6.3	4.7	1.0	18.3	Young and Grant, 1931
Goat	3.8	3.5	4.1	0.8	12.2	Park, 2006a
Guinea pig	3.9	8.1	3.0	0.82	15.8	Smith, 1959
Horse	1.21	2.14	6.37	0.42	10.14	Park *et al.*, 2006
Human	4.0	1.2	6.9	0.2	12.3	Park, 2006a
Kangaroo[a]	2.1	6.2	trace	1.2	9.5	Bolliger and Pasco, 1953
Mink	8.0	7.0	6.9	0.7	22.6	Jorgensen, 1960
Monkey	3.9	2.1	5.9	0.3	12.3	Smith, 1959
Moose	7.0	13.5	3.6	1.6	25.7	Ben Shaul, 1962
Mouse	12.1	9.0	3.2	1.5	25.8	Ben Shaul, 1962
Mule	1.8	2.0	5.5	0.5	9.8	Altman and Dittmer, 1961
Musk ox	11.0	5.3	3.6	1.8	21.7	Evans, 1959
Opossum	6.1	9.2	3.2	1.6	24.5	Gross and Bolliger, 1959
Rabbit	12.2	10.4	1.8	2.0	26.4	Bergman and Turner, 1937
Rat	14.8	11.3	2.9	1.5	31.8	Altman and Dittmer, 1961
Reindeer	11.1	11.1	3.0	1.5	27.1	Aikio and Nieminen, 1998
Sea lion, CA[b]	34.9	13.6	0.0	0.6	49.1	Pilson and Kelley, 1962
Seal						
Gray	53.2	11.2	2.6	0.7	67.7	Amoroso *et al.*, 1951
Hooded	40.4	6.6	?	0.9	47.9	Ben Shaul, 1962
Sheep	7.1	5.7	4.6	0.9	18.4	Recio *et al.*, 2009
Swine	5.8	10.6	3.4	0.73	20.5	Park, 2006b
Whale	34.8	13.6	1.8	1.6	51.2	Altman and Dittmer, 1961
Yak	5.11	5.25	5.53	0.79	16.19	Li *et al.*, 2011
Zebra	4.8	3.0	5.3	0.7	13.8	Altman and Dittmer, 1961
Zebu	4.3	3.7	4.3	0.8	13.4	Bonfoh *et al.*, 2005

[a] Marsupial.
[b] CA is California.
Source: Park and Haenlein (2006). Reproduced with permission of John Wiley & Sons.

The First Edition was published with 12 main chapters with 5 subchapters in the goat milk chapter and 3 subchapters in the buffalo milk chapter. For the Second Edition, two more chapters have been added to expand from 12 chapters to 14 chapters. Brief summaries of highlights of each of the 14 chapters in this book are as follows:

Chapter 1. Overview of Milk of Non-Bovine Mammals. This chapter describes the general overview of the contents of this Second Edition and the needs and justification for this publication.

Chapter 2. "Goat Milk" has been written as four subchapters, with one subchapter on flavor characteristics separated to make an independent chapter as Chapter 12 to cover flavor and sensory characteristics of non-bovine species milk. This goat milk chapter has been updated to include recent information on quality maintenance to limit the potential for lipolysis on the smaller volumes of raw milk toward the end of lactation. Goat milk has been the most available milk, for beverage milk sales, throughout the world. Cheese is the primary manufactured product from goat milk consumed in large volumes around the world.

Chapter 3. "Sheep Milk" has been expanded to three subchapters, similar to "Goat Milk," to allow for a wide discussion on increasing sheep milk production. Sheep will generally yield about one-third of the volume of milk that goats produce on a daily basis. Therefore the research emphasis on dairy sheep is for increased production.

Chapter 4. "Buffalo Milk" has been updated with three subchapters, as had been written in the First Edition. In terms of the volume of world milk supply, buffalo is the second highest milk producing dairy species, so recent scientific progress and literature on the production and utilization of buffalo milk have been updated and expanded.

Chapter 5. "Mare and Donkey Milk" has been expanded to cover not only the updated discussion on mare milk but also donkey milk. This chapter has been updated for horse milk production and processing, and animal management, as well as nutritional, functional, and health-promoting characteristics in a sustainable and multifunctional dairy chain that would enrich the human diet.

Chapter 6. "Camel Milk" has added updated reports on camel population, its milk composition, milk enzymes, milk products, immune system, and medicinal properties. Camels support the survival of millions of people in arid and semi-arid regions of the world.

Chapter 7. "Yak Milk" is produced by one of the world's most remarkable domesticated animals (*Poephagus grunniens or Bos grunniens*), which thrives in extreme harsh conditions and deprivation while it provides milk and animal products for yak keepers. Recent research data of yak milk composition have been extensively discussed, and its milk products are also included.

Chapter 8. "Zebu and Mithun Milk" is a new chapter in the Second Edition of the Handbook that covers the livestock from the tropical regions such as the North Eastern Region of India and South America. A zebu (*Bos primigenius indicus* or *Bos indicus* or *Bos taurus indicus*), sometimes known as indicine cattle, humped cattle, or Brahman, is a species or subspecies of domestic cattle originating in South Asia. Zebu are used as draught oxen, as milk, meat, hide, and manure (fuel). Mithun (*Bos frontalis*) is the gift of rich biodiversity, which is a magnificent domesticated animal of the Bovidae family and is a distant relative of cattle and buffaloes. Mithun milk is found to be suitable for human consumption. The uniqueness of the milk of these two species will be covered in this chapter.

Chapter 9. "Reindeer Milk" is important for the economy and wellbeing of people in northern Eurasia and taiga regions. This chapter further dissects biological constraints of the production, composition, and potential yield of reindeer milk. Discussions are extended for the potential of establishing a new niche-based milking industry with ecological and economical considerations.

Chapter 10. "Sow Milk" has been updated with recent reports. Since humans and pigs share similar digestive and physiological systems, knowledge of the mammary growth, physiology, maternal nutrition, and lactogenesis of sow milk and its chemical compositions would be important information applicable to human lactation, nutrition, and health research.

Chapter 11. "Other Minor Species Milk" of domesticated and wild mammalian species are discussed and updated in this chapter. The current scientific research data on minor species such as moose, elk, musk ox, alpaca, llama, elephant, pinnipeds, and polar bear have been compiled and described.

Chapter 12: "Flavor and Sensory Characteristics of Non-Bovine Species Milk and Their Dairy Products" discusses the uniqueness of flavor traits and sensory properties of non-bovine species milk and their products. These minor species milk would possess specific components and characteristics that are absent and/or different from those in cow milk.

Chapter 13. "Potential Applications of Non-Bovine Mammalian Milk in Infant Nutrition" deals with the potential use of non-bovine milk components and the advantages of nutritional sources in the feeding of infants. Although a mother's milk is the most ideal and universally recommended nutrient source for human infants, an alternative is necessary when effective breast-feeding is not possible or practiced. The chosen alternative is an infant milk formula based on bovine milk, but this chapter explores the milk of other species that are closer to the composition of human milk than bovine milk.

Chapter 14. "Human Milk" is thought to be the best form of nutrition for neonates and infants. This chapter delineates the major premises involved in the current trends of infant feeding, composition, production, and feeding practices of human milk in relation to infant growth, nutrition, and human health.

5 Concluding Remarks

The editors of this Second Edition have assembled expert scientists in the field of non-bovine mammalian species from around the world to contribute to this book, covering domesticated and wild species milks including goat, sheep, buffalo, mare, camel, yak, reindeer, sow, donkey, zebu, mithun, moose, caribou, musk ox, elk, pinniped, polar bear, and human. This book is expected to serve essential textbook or scientific references for dairy scientists, food chemists, nutritionists, allergy specialists, and health professionals. This publication would be an important resource book for master and artisan cheesemakers and dairy plant personnel. As was true of the First Edition, this Second Edition may also be adopted as a textbook for graduate and undergraduate students in food/dairy science.

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