Nutritional Parameters in Colostrum of Different Mammalian Species

Subjects: Agriculture, Dairy & Animal Science

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Colostrum (or first milk) is the food produced by all the mothers in all specific mammalian species, ruminants, monogastric and marine mammalians for their newborns during the first 24–48 h post-partum. Colostrum provides to the neonate all essential nutrients necessary for the first week of life, but the effect of colostrum shows a long-term effect not limited to these first days. Colostrum is considered to be a safe and essential food for human consumption. Some young children can show at the beginning of their colostrum-based diet some side effects, such as nausea and flatulence, but they disappear quickly. In human colostrum, the immunoglobulins and lactoferrin determined show the ability to create natural immunity in newborns, reducing greatly the mortality rate in children.

Keywords: milk ; colostrum ; mammalian species ; infant nutrition

1. Human Colostrum

Health benefits provided by Human Colostrum (HC) were discovered several years ago [1]; the gastrointestinal system in newborns is small and immature, and HC is the only food able to provide the required nutrients at the right adequate levels.

Compared to mature Human milk (HM), HC in fact is rich in bioactive compounds containing immune and growth factors useful for the newborn protection against infectious diseases and also able to guarantee in the first 24 h of the newborn life gut microbiome healthy growth. In fact, thanks to prebiotic action, HC stimulates the immune system of the newborn, thus compensating for the immunological lack that characterizes preterm infants [2][3]. Civra and co-workers [2] found that HC possesses intrinsic antiviral activity against rotavirus and respiratory syncytial virus and that the extracellular vesicles (EVs) give a great contribution to the overall protective effect. The EVs include exosomes and microvesicles with a size ranging from 50 to 200 nm, which are released by several tissues including HM, and structurally are characterized by a lipid bilayer that encloses several molecules such as signaling proteins, mRNA, miRNA, and enzymes. EVs are taken up by other cells where they release the content of their molecules that exert their different role (intercellular signaling, immune response, viral replication, neuronal function, and tissue regeneration) [2].

HC plays an important role in newborns, due to its laxative effect, helping the baby in the passage of the initial stools called meconium, and also eliminating the excess of bilirubin from the baby's intestine, preventing jaundice [3][4]. Antibodies in colostrum not only protect neonates against infectious diseases [5] but also provide passive immunity and growth factors for gastrointestinal development [6].

HC is considered a safe food for a large part of the human population; sometimes, side effects such as nausea and flatulence may appear in the first 48 h, then these symptoms decline after the second day. HC consumption must only be avoided for consumers showing milk allergies, intolerance to milk-based products, or people showing galactosemia [7].

Total protein can be considered the sum of caseins and whey proteins, with both components showing nutritional and bioactive properties [8]. Casein is the most represented phosphoprotein in dairy cows' milk; the αs1-casein fraction is the predominant protein in bovine milk [9]. Human casein is characterized by peptides with opioid-type activity, affecting immune activity in children and helping the adsorption of other biologically active peptides [10]. Human casein consists of several sub-units, which form micelles with Ca^{++} and PO_4^- causing the typical white color of milk [11]. The micelles in human casein are spherical colloidal particles, with an average size of 50 nm, containing around 94% protein and 6% non-protein species, mainly calcium and phosphate, called colloidal or micellar calcium phosphate (CCP or MCP) [11]. In several mammalian species, milk is supersaturated with calcium phosphate and the insoluble part (CCP) is present in the casein micelles; human milk has a small amount of CCP compared with ruminant species, and its micelles show a porous structure [11].

2. Bovine Colostrum

Bovine colostrum (BC) is a thick yellowish liquid containing a higher concentration of antibodies compared to mature milk [12]. Protein content in BC is higher compared to mature milk: protein fractions can be classified into two groups: whey proteins and caseins [13]. Caseins are the most abundant phosphoproteins in cow milk, being around 75% of total proteins [14]. Whey proteins include immunoglobulins, lactoferrin, α-lactalbumin, β-lactoglobulin, lactoperoxidase, and several growth factors [15]. α-lactalbumin is the most abundant peptide determined in BC whey proteins, being about 40% of total whey proteins, showing a high content of essential amino acids [16]. β-lactoglobulin contains 162 amino acids, being a good source of essential amino acids, but sometimes can be considered a major immunogen for people affected by cow milk protein allergies [17]. Lactose represents the most abundant carbohydrate in BC, being about 2.5%, a lower amount compared to mature bovine milk or human milk [18]. Lactose is a disaccharide formed by galactose and glucose; it plays an important role in the liver, supporting glycogen synthesis and storage [19]. Dietary oligosaccharides content in BC is around 1 g/L, about double the level compared to mature milk [20]. Most of them are not digested in the upper intestine, so they can play a prebiotic role, passing intact into the colon portion of the intestine, where they can represent a metabolic substrate for colonic bacteria [21]. Fat content in BC is around 7%; the lipid fraction contains several molecules of potential health relevance, including ω-3 and ω-6 essential fatty acids, conjugated linoleic acid, and phospholipids. The BC lipid profile is characterized by around 65–75% of saturated fatty acids, 24–28% monounsaturated fatty acids, and 4–5 polyunsaturated fatty acids [22]. Palmitic acid (about 40%) and oleic acid (21%) are the two most represented total fatty acids [21], confirming the importance of palmitic acid in infant nutrition [23], while oleic acid is involved in other health benefits related to the immunomodulation and to the cardiovascular system [24]. Fat-soluble (A, D, and E) and water-soluble (B-complex) vitamins are both represented in BC, being involved in several metabolic processes including bone growth and antioxidant activity. Vitamin D plays also an important role in supporting immune system function and mental health [25]. Vitamins and minerals concentrations in BC are higher compared to mature milk [26][27].

3. Donkey Colostrum

Donkey foals, because of the type of placentation, require a good amount of high-quality colostrum, to achieve an adequate serum IgG concentration at 24 h of life [28]. The donkey placenta, in fact, is diffuse, epitheliochorial, and shows several microplacentomes consisting of a fetal microcotyledonary and a maternal microcaruncular part [28]. A reduced consumption or the availability of low-quality colostrum in newborn foals can easily lead to common negative health conditions, provoking sepsis, which can manifest in several different ways, such as bacteremia, pneumonia, enterocolitis, and septic arthritis [28].

The chemical composition of the donkey milk changes quickly in the first week of lactation; in particular, donkey colostrum (DC) shows higher concentrations of protein, Igs, lactoferrin, β-lactoglobulin, and fat, and lower lactose content compared with mature milk, while lysozyme content is similar in both colostrum and mature milk [29]. Some authors have suggested that DC could be an appropriate substitute for HC, considering the high similarity in chemical composition between human milk and donkey milk. For these reasons, in several studies, children affected by Cow Milk Protein Allergy have been treated by administering donkey milk; this is considered by several pediatricians a natural and safe replacer of human milk in infant nutrition [30].

A detailed study was performed in order to determine the physico-chemical characteristics and somatic cell count of DC during the first ten days after foaling; a decreasing trend was observed for protein, dry matter, and ash levels [31]. The lowest values for lactose and pH were detected in the first hours (4.01 g/100 mL of milk and 6.69 pH units), while protein content showed a peak (10.2 g/100 mL of milk) at 0 h. Basically, the colostrum phase in donkeys lasts about 12–24 h, after which the secretion can be considered transitional milk [32].

Several studies have been performed on donkey milk in order to evaluate its lipid content, characterized by a high percentage of essential fatty acids, with an n–3:n–6 series ratio of 0.86 [31]. DC mineral content emphasizes a balanced proportion of both macro-elements K, P, Ca, Mg, Na, and micro-elements, Cu, Zn, Ni, Cd, and Fe [33]. The most important nutritional characteristics of donkey milk can be attributed also to the health status of the donkey's mammary gland, which is correlated to the innate immunity of donkey's udders [34][35]. Lactoferrin, lactoperoxidase, and lysozyme are considered the most important bioactive peptides detected in donkey milk and donkey milk colostrum, considering their crucial role played as antimicrobial agents [36]. During the lactation period, these proteins show significant changes in their content; colostrum has higher lactoferrin and β-lactoglobulin concentrations compared to raw milk, while the lysozyme content has been determined at similar levels in colostrum and fresh mature milk [37].

4. Goat Colostrum

Colostrum chemical composition in various mammalian species differs significantly in nutrient content; the variations determined in some ruminant species reflect different adaptive strategies [38]. Data are available for milks of nearly 200 of the more than 4000 existing mammalian species [39]. Milk water content ranges from about 90% (in kangaroo) to 34.6% (in fur seal), while fat content ranges from almost 1% (in donkey) to more than 50% (in fur seal); aquatic mammals typically have high milk fat content percentage. Milk protein content differs significantly among species but not so much as milk fat, ranging from approximately 1% (in human) to about 14% (in whale). Lactose ranges from trace (in kangaroo) to 7.4% (in donkey), while minerals range from almost 0 to 2% [40].

Goat colostrum (GC) is a good source of nutrients such as proteins, lactose, fat, and micronutrients including vitamins and minerals, and it is also characterized by several biologically active compounds [41]. These include antimicrobial proteins (Lactoferrin), Epidermal Growth Factor (EGF), Insulin-like Growth Factor-I (IGF-I), and Immunoglobulin G (IgG). GC shows, compared to mature milk, significantly higher contents of protein, fat, minerals, Dry Matter, EGF, and IGF-I, while lactose concentration is lower. GC plays an important role in the nutrition, protection, and development of the newborn, taking part in the immunological defense of the kids, stimulating the immune system, or providing passive protection, especially in the gastrointestinal tract [42]. A large part of GC molecules come directly from the bloodstream (i.e., Ig, somatotropin, prolactin, insulin, and glucagon), while others (fat, lactose fat, lactose, caseins, α-lactalbumin, β-lactoglobulin and so on) are produced directly in the udder from mammary epithelial cells and the stroma [43].

GC contains high concentrations of Ca, P, and Mg, and low concentrations of Zn, Fe, Cd, As, Pb, and Hg [41]. Moreover, 25% of the fatty acids in GC belong to the category of unsaturated fatty acids, compared to 40.8% for bovine milk fat and 60.8% for human milk fat. In GC, BC, and HC, the ratios of saturated to unsaturated fatty acids were calculated, obtaining the values of 3.03 in GC, 1.10 in BC, and 0.57 in HC [44].

5. Alpaca Colostrum

Alpacas and llamas are domesticated species of South American Camelids [45]. Because of the epitheliochorial placenta of alpacas, their newborns lack gammaglobulins; therefore, they receive from their mothers' high-quality colostrum to achieve passive humoral protection against infectious diseases via intestinal absorption [46]. When the alpaca mother does not provide enough colostrum, or poor quality colostrum, or, in the worst scenario, dies during parturition, it is important to provide good colostrum replacers for the newborns. To prepare colostrum replacers, it is important to know in detail the composition of alpacas' colostrum.

Fat content in colostrum increased significantly from day 1 to day 4, then the fat level was similar to the value determined in mature milk. Lactose content on the day of parturition was lower compared to the following days 2, 3, and 4. Colostrum protein content decreased significantly during the first 4 days but remained higher compared to the levels determined in mature milk [47]. The average total amount of colostrum hand collected from each animal was 20.8 mL, without significant differences among the days.

The fat, protein, and lactose content in alpacas' colostrum changed substantially during the following lactation stages. The decrease in protein concentration and the increase in fat content confirm the trends registered in other mammalian species [48]. The significant decrease in protein content during the colostrum phase can be determined by the strong reduction in immunoglobulin concentration, which is a frequent condition in most of the colostrum produced by the most common dairy mammalian species [49].

6. Mare's Colostrum

Mare's colostrum is crucial during the first weeks of life for the foal; if the mare dies, it is essential that the foal receives a milk replacer adequate for its feeding requirements. The mares' udder consists of two smaller caudal glands and two larger cranial glands, but sometimes six glands can occur [50]; each quarter consists of one gland cistern and one teat cistern. Mares' milk can also represent an important food for the human population [51], especially in the feeding of children showing IgE-mediated cow milk allergy [52]. The average daily milk production for a lactating mare can be estimated at around 2–3.5% of the horse's bodyweight per day, so a mare weighing 500 kg produces around 10–18 kg of milk per day [53].

The dry matter content in a mare's colostrum is around 25% while the mare's mature milk shows a dry matter content of 10–12%, which decreases throughout the lactation [54]. The fat content in the milk of mares is relatively low with an average of around 1–1.5% [55]. The fat content also varies during the lactation period, with an overall decrease in fat content from colostrum to the end of lactation [56]. Fat content in a mare's colostrum is affected by the number of parturitions registered by the mare: the more the foals, the higher the fat content in the colostrum [57][58].

The protein in mares' milk is on average close to 2%; this value decreases over the lactation period, and the highest decrease in protein occurs during the colostrum period [59]. Pre-albumin is a peptide belonging to the whey protein category and is only detected in the colostrum. Immunoglobulins also belong to whey proteins and show a high concentration at the beginning of the colostrum period, starting to decrease both during the colostrum phase and during the whole lactation period [60]. The content of the whey proteins α-globulins and albumins increase from the colostrum to the mature milk [61].

7. Ewe's Colostrum

The importance of milk and dairy products in human nutrition has been well-known for a long time; for this reason, functional dairy foods are considered a novel attractive dietary option, having the advantage of being ‘‘natural'' products, and therefore better accepted by consumers [62]. Most of the studies concerning dairy foods have focused on bovine milk, which is the most common milk used in human nutrition in a large part of the world [63]. In recent years, studies concerning the functional and nutritional attributes of milk from other mammalian species increased [64]. The use in human nutrition of milk from small ruminants, especially goat and ewe milk, has recently received special attention due to some interesting nutritional quality parameters affecting human health [65]. In fact, studies on the minor bioactive components of ewe and goat's milk are still quite limited, such as the nutritional properties of small ruminant colostrum. In a study performed on ovine milk, colostrum collected from 84 Rambouillet primiparous ewes showed a yield on day 1 ranging from 378.4 to 579.3 g/d, with a protein content close to 16.6%, fat content around 12.5–14.1%, and lactose content of 2.32–2.62% [66]. Ewe's mature milk was collected 20 days after parturition, and showed significant differences compared to colostrum: milk yield ranged from 749.2 to 960.8 g/d, protein content was 5.11–5.38%, fat concentration ranged from 5.66 to 6.60%, and lactose content was 5.10–5.20% [66]. Ewe's colostrum shows the highest Total Solid content compared to other dairy ruminants such as cow or goat; lipid content was 9.11% for ewe's colostrum and decreased to 5.65% for cow colostrum, and to 4.88% for goat colostrum [67]. Colostrum of Awassi ewes showed a content of 60.9 ± 21.4 mg/mL of IgG; colostrum obtained from primiparous ewes showed higher IgG levels compared to the values determined in multiparous ewes [67].

Interesting work has been performed to determine the polyamine concentrations in both ewe and goat colostrum and milk, on the first post-partum day and later after two weeks of lactation. Polyamine pool determination in both kinds of milk gave valuable scientific data concerning the dietary aspects of these two milk categories, creating the possibility of using them in the preparation of quality-oriented dairy products and introducing them in the market of novel dairy foods [65].

Putrescine was not detected in mature goat milk (15th day), while Spermidine was the most abundant polyamine in goat milk. In ewe's milk, spermidine and spermine contents were comparable among colostrum and mature milk. Mature ovine milk (15th day) showed higher polyamine content compared to goat milk, but caprine colostrum had a higher total polyamine content compared to ewe's one.

The possibility of creating novel dairy foods with enhanced nutritional benefits for specific consumer categories is really appealing. Furthermore, the possibility of using ewe or goat milk or their colostrum in clinical trials is very interesting, due to the important role these nonpeptide nitrogenous molecules play in homeostatic cell regulation.

8. Camel's Colostrum

The use of non-bovine milk for feeding children can be effective in reducing the development of gastrointestinal disorders [68]. Goat milk was investigated firstly, and later in the 1990s, donkey milk started to arouse great interest in clinical trials [68]. Recently, the use of camel milk to replace dairy cows and other kinds of milk (goat, donkey, and mare) has attracted interest in the scientific community [69]. Camel milk's antiallergenic properties are also due to the similar protein profile compared to human mother's milk, with the absence of β-lactoglobulin and a high concentration of α-lactalbumin [70]. Camel whey protein shows a high content of anti-microbial factors such as lysozyme, lactoferrin, and immunoglobulins [71][72]; other whey proteins have been identified in camel milk including serum albumin, immunoglobulins, lactophorin, and peptidoglycan recognition protein [73]. Considering the different chemical composition of camel colostrum and camel mature milk, fat and protein contents decrease greatly in the post-partum period: seven days after calving, total fat fell to an eighth of its previous value (25.9% vs. 3.1%), while total protein was divided by four, falling from 17.2% to 4.2%. Lactose concentration showed values very close to each other, without significant differences among different animals. In camel colostrum, any significant difference was observed regarding the Non-Protein-Nitrogen content, which remained stable all through the lactation period [74].

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