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The overall and fat composition of milk of various species

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Abstract

Milk, an essential source of offspring nourishment, varies in its composition and properties significantly across species. In human nutrition, fresh milk and dairy products are valuable sources of protein, fat and energy, and are an important part of daily meals. Most of the world's milk production (85 %) comes from cows followed by buffaloes, goats, ewes, mares and donkeys. However milk related food allergies in infants may be a reason for health problems and may cause a decrease in milk. The objective of this paper was to give an overview of the overall composition of milk and fat from different species in comparison to women milk. Regarding the overall milk composition remarkable differences in energy content, fat, lactose, protein and ash of the various milks were found, but also some similarities among milk from ruminants and non-ruminants were detected. The structures of fat globule membranes were similar among non-ruminants and women milk, while the milk fat globule structure in ruminants differed significantly. The size of fat globules was significantly different between species and highly correlated to the milk fat content, regardless of the specie. The amount of triacylglycerols was notably higher, while the amount of free fatty acids and phospholipids was notably lower in milk from ruminants and women compared to milk from mares and donkeys. The triacylglycerol structure in women and non-ruminants' was similar. The percentage of saturated and monounsaturated fatty acids was lower, while the unsaturated fatty acid content was higher in milk from non-ruminants, with a remarkably higher percentage of C-18:2 and C-18:3. The cholesterol content was similar in women and ruminants' milk, but lower in that of non-ruminants. This review indicates that milk from non-ruminants could be more suitable for human nourishment than milk from ruminants.

Key words: mammalian species, overall milk composition, fat milk composition

Introduction

Generally, milk presents an essential source of nourishment of offspring during the early postnatal period. In the human nutrition, fresh milk and dairy products are valuable sources of proteins, fat, and energy and represent an important part of daily meals. Cows' milk is most commonly consumed with 85 % of total milk quantity produced worldwide. According to Gerosa and Skoet (2012), 11 % of world milk production came from buffalo, followed by

2.3 % from goats, 1.4 % from sheep, and 0.2 % from camels. Milk from horses and donkeys contribute less than 0.1 % of the global milk production. Regarding the milk consumption, problems can occur in infants if cows' milk was used as a substitute for women milk. Using cows' milk as a substitute during infancy and early childhood may cause food allergy to cows' milk with a prevalence of approximately 2.5 % during the first 3 years of life (Businco et al., 2000). Allergies and intolerance to milk are caused by the different composition of various

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milks. The composition of milk corresponds to the requirements of the offspring, which differs from species to species. Therefore, milk composition is highly dependent on animal species.

The main objectives of this paper were to compare the overall milk and fat composition of milk from different species and to discuss similarities in comparison to women milk since some milk species (e.g. horse, donkey and ewe milk) are currently promoted as a more suitable alternative to breast milk and infant formula.

Overall milk composition

Regardless of the species, milk is composed of the following main components: fat, protein, lactose and ash. Differences in components content due to animal species are shown in Figure 1, which provides mean values of milk composition reported in the relevant literature. Some similarities regarding the milk composition between non-ruminants and ruminants milk are evident. Comparing to ruminants, milk from non-ruminants (mare's and donkey's) contain a lower content of the total dry matter

(TDM), fat, protein, and ash as well as a lower energy value. Also, more lactose is present in milk from non-ruminants than ruminants. The mean values of TDM, protein, lactose and ash are similar in milk from non-ruminants and women.

Even within the same species, the milk composition can vary due to genetics (not only at species but also at breed and individual level), physiology (parity, lactation stage, milking interval), nutrition (feed energy value and composition) and environment (location, season). The ranges of overall milk composition from various species according to the literature are presented in Table 1. The overall composition of the compared milk species differed remarkably in terms of energy value. Milk from buffaloes and ewes had noticeably higher energy value (420-480 kJ/100 g and 410-440 kJ/100 g) compared to other milks, while milk from mares and donkeys has the lowest energy value (less than 210 kJ/100 g and 180 kJ/100 g). Similar energy values are in milk from goats, cows, and women.

Regarding the ash content, similar ranges were found in milk from ruminants, which were remarkably higher (≥ 0.7 g/100 g) than those found in milk from donkeys, mares, and women (≤ 0.5 g/100 g).

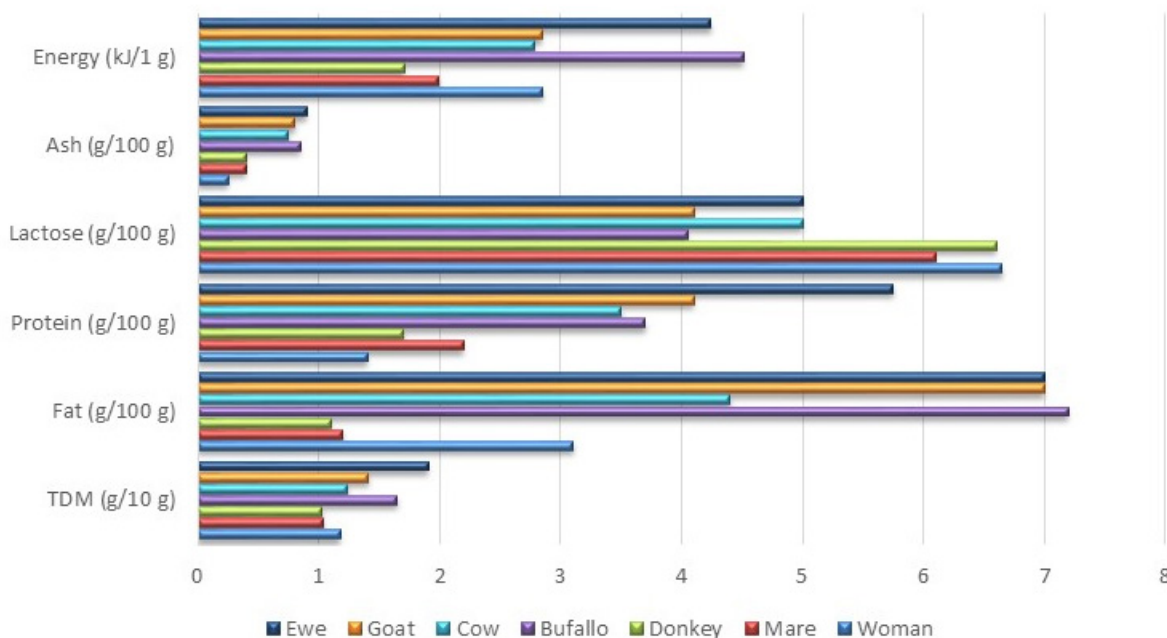


Figure 1. Overall milk composition of different animal species - mean values reported in literature (Jenness and Sloan, 1970; Solaroli et al., 1993; Mariani et al., 1993, Salimei, 1999; Guo et al., 2007; Giosuè et al., 2008; Hassan et al., 2009; Potočnik et al., 2011; Salimei and Fantuz, 2012; Čagalj et al., 2014; *TDM - total dry matter)

Table 1. The overall milk composition from different animal species - interval values (minimum and maximum) reported in literature (Jenness and Sloan, 1970; Solaroli et al., 1993; Mariani et al., 1993, Salimei, 1999; Guo et al., 2007; Malacarne et al., 2002; Park al., 2007; Varrichio et al., 2007; Giosuè et al., 2008.; Hassan et al., 2009; Potočnik et al., 2011; Salimei and Fantuz, 2012; Čagalj et al., 2014)

Milk	TDM (g/100 g)	Fat (g/100 g)	Protein (g/100 g)	Lactose (g/100 g)	Ash (g/100 g)	Energy (kJ/100 g)
Woman	10-13	2.1-4.0	0.9-1.9	6.3-7.0	0.2-0.3	270-209
Mare	9-12	0.4-7.2	1.3-2.0	6.0-7.2	0.3-0.5	109-210
Donkey	8-12	0.3-1.8	1.4-2.0	5.8-7.4	0.3-0.5	160-180
Buffalo	16-17	5.3-15.0	2.7-4.7	3.2-4.9	0.8-0.9	420-480
Cow	12-13	3.3-6.4	3.0-4.0	4.4-5.6	0.7-0.8	270-280
Goat	12-16	3.0-7.2	3.0-5.2	3.2-4.5	0.7-0.9	280-290
Ewe	18-20	4.9-9.0	4.5-7.0	4.1-5.9	0.8-1.0	410-440

*TDM - total dry matter

Lactose content was the highest in milk from women, mares, and donkeys (≥ 5.8 g/100 g) and lowest in milk from buffalos and goats (≤ 5 g/100 g). Protein content (0.9-1.9 g/100 g) was the lowest in women milk. The protein content of milk from mares and donkeys was intermediate (≥ 0.7 g/100 g), while milk from ruminants had the greatest protein content. The greatest protein content was found in milk from ewes (to 7 g/100 g). Also, there was a wide range of values for fat content. From ruminants, the greatest fat content was in milk from buffalos (max value 15 g/100 g) and the lowest in milk from cows (min value 3.3 g/100 g). The low fat content was found in milk from donkeys and mares. The fat content of women milk (2.1-4 g/100 g) was greater than that of non-ruminants, but less than that of ruminants. The higher fat content of buffalo milk makes it highly suitable for processing. For example, the production of 1 kg of butter requires 14 kg of cow milk versus 10 kg of buffalo milk. In many countries, buffalo milk is used to make traditional cheeses, such as Mozzarella or Ricotta in Italy. Overall, similarities of milk components (energy value and content of fat, protein, lactose, and ash) exist within ruminants and non-ruminants. Stoyanova et al. (1988) and Marconi and Panfili (1998) stated that regarding the overall composition, milk from non-ruminants might be a more suitable source of nourishment for infants than milk from ruminants.

Structure and size of fat globules

Lipids in milk are dispersed in a form of emulsified globules. Milk fat globules are coated by a biological membrane that results from the secretion mechanisms of fat globules from the epithelial cells of the mammary gland (Lopez et al., 2008). These membranes are rich in proteins, glycoproteins, glycerophospholipids, sphingolipids, cholesterol, enzymes and other minor components (Keenan and Patton, 1995). Fat globules in mare's milk are coated with three layers - the internal protein layer, the intermediate layer consisting of phospholipid membrane and the external layer consisting of glycoproteins. On the surface of these glycoproteins is a branched oligosaccharide structure that is similar to the fat globules in women milk, (Solaroli et al. (1993). This array of glycoprotein filaments may enhance digestion by binding lipases (Jensen et al., 1990; Koletzko and Rodriguez-Palmero, 1999). The fat globules in cow milk are coated by a thin protective film with external layers comprised of proteins and phospholipids without glycoproteins (Jensen et al., 1990; Malacarne et al., 2002). Claeys et al. (2014) reported that the structure of the fat globule interface significantly affected the fat digestibility because gastric lipases must pass through this interface to gain access to the triacylglycerols. According to the

same authors, the physico-chemical changes at the interface due to heating and homogenization seemed to positively affect lipase access to the triacylglycerols and, thus, the milk digestibility. These similarities among the milk of women and non-ruminants, relative to the structure of fat globule membranes, possibly could enable easier fat digestion. Hence, milk from non-ruminants could be assumed as more suitable for human nourishment.

Milk fat globule sizes, as the factor that affects fat digestibility, differs among species. The mean values of the average diameter of milk fat globules reported in literature are presented in Figure 2. The smallest diameter are found for milk fat globules in mare's milk (ranging from 2 to 3 μm ; Kharitonova, 1978; Welsch et al., 1988; Devle et al., 2012), while the largest diameter are associated to milk fat globules in buffalo's milk (ranging from 5 to 8.7 μm ; El-Zeini, 2006; Ménard et al., 2010).

Milk with a high fat content, such as buffalo's milk, usually contains larger fat globules than milks with a lower fat content (El-Zeini, 2006). Thus, the specific surface area is significantly higher for smaller fat globules relative to larger fat globules (Ménard et al., 2010). Also, there is a positive, linear relationship between the fat globule size and the fat content of milk (Ménard et al., 2010). The formation of larger fat globules during the synthesis of

milk fat is explained by the limitations on the production of the milk fat globule membrane when fat globules are enveloped during their secretion from the epithelial cells of the mammary gland. It is concluded that milk fat globule membrane could be a limiting factor in the formation of small fat globules in high-fat content milks, such as buffalo milk.

The physicochemical properties of the milk fat globule membrane are primarily important in the physical stability of fat globules in milk (Ménard et al., 2010). Phospholipids are excellent emulsifying agents and the milk fat globule membrane prevents fat globules from aggregating and coalescing. The milk fat globule membrane is also a physical barrier against the hydrolysis of triacylglycerols by lipolytic enzymes. The larger milk fat globules (characteristic of milk with a high fat content) may have a less stable membrane of the milk fat globule and decreased resistance to deformation and coalescence under mechanical pressure compared to smaller fat globules (characteristic of milk with low fat content). Hence, the larger size of milk fat globules in milk with higher fat contents may facilitate their disruption during processing. Moreover, large fat globules have the ability to rapidly move up and transition out of the aqueous phase to form a cream layer at the milk's surface. Regarding the digestibility of milk fat, the smaller the fat globule, lipid metabolism is more efficient.

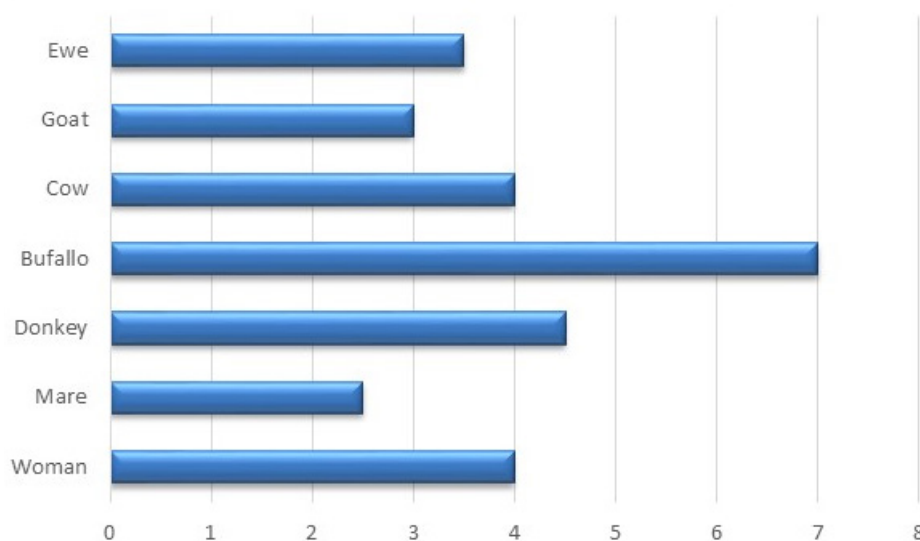


Figure 2. Milk fat globules average diameter in μm - mean values reported in literature (Kharitonova, 1978; Welsch et al., 1988; El-Zeini, 2006; Ménard et al., 2010; Devle et al., 2012)

On average, fat globules in mares' milk are smaller than that of donkeys, cows, ewes and goats. These fat globules are smaller than that in buffaloes' milk

Fatty acids composition

Fat globules are mainly composed of triacylglycerols, which are esters of glycerol and fatty acids. Determination of the amount of triacylglycerols, free fatty acids, and phospholipids in milk from various species was the objective of multiple studies (Doreau and Martin-Rosset, 2002; Jensen et al., 1990; Malacarne et al., 2002; Park et al., 2007; Uniacke-Lowe, 2011; Claeys et al., 2014). The triacylglycerols comprise only 80-85 % of the fat in milk from mares and donkeys, while the triacylglycerol content in fat of milk from ruminants (cow, buffalo, sheep, and goat) and women is much greater (97-98 %; Claeys et al., 2014). Also, there is a higher content of free fatty acids (9.5 %) and phospholipids (5-10 %) in mares' and donkeys' milk compared to milk from ruminants and women (0.5-1.5 % of phospholipids and 0.7-1.5 % of free fatty acids). Due to the potential anti-carcinogenic effects of phospholipids, especially the protective effect of sphingomyelin against colon cancer (Berra et al., 2002), milk from these non-ruminants could be considered as a functional food. The number of carbon atoms in di- and tri-glycerides is an identifiable character-

istic of the milk from particular species (Parodi, 1982). The distribution of milk fat molecules in milk from non-ruminants and women typically follows a unimodal pattern with a maximum of 50-52 carbon atoms, while in milk from ruminants milk fat molecules are distributed in a bimodal pattern with two maximum values (the first ranging from 34 to 40 carbon atoms and the second from 42 to 54; Pagliarini et al., 1993).

From a nutritional point of view, the triacylglycerol structure is one of the main factors that affects fat absorption through the action of lipolytic enzymes. The distribution of fatty acids on the glycerol backbone determines the efficacy lipolysis and the bioavailability of fatty acids (German and Dillard, 2006). The distribution of fatty acids determines their possible beneficial or detrimental effects on health. Palmitic acid (C-16:0) in women milk is preferably located in the sn-2 position, which is considered favourable for the assimilation of this fatty acid in children (Winter et al., 1993). The C-16:0 in milk from mares and donkeys is also preferentially associated with the sn-2 position, while the C-16:0 of cows' milk has equally beneficial functions when located in the 1 or 2 positions (Parodi, 1982; German and Dillard, 2006). In cow milk, fatty acids with lengths from C-4:0 to C-10:0 are mainly esterified at the sn-3 position (Gastaldi et al., 2010; Jensen et al. (1990).

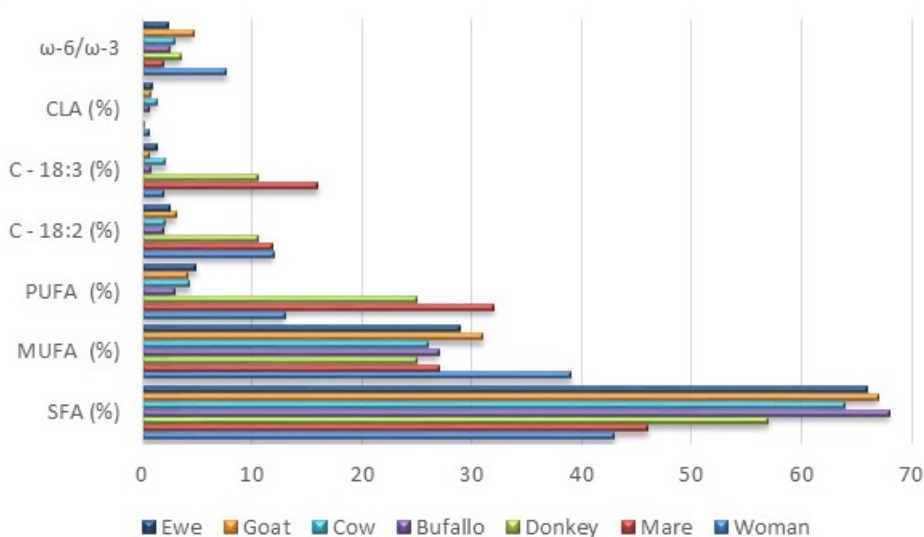


Figure 3. Fatty acids profile of different species - mean values reported in literature (Doreau and Martin-Rosset, 2002; Jensen et al, 1990; Malacarne et al., 2002; Park et al., 2007; Gastaldi et al., 2010; Uniacke-Lowe, 2011)

Milk fat, regardless of the species, contains mainly saturated fatty acids (SFA) of various chain lengths and lower amounts of unsaturated fatty acids. The fatty acid composition of milk is a function of the species, the breed, and the stage of lactation, the environment, and the plane of nutrition. Generally speaking, the milk fat from non-ruminants (mare and donkey) contains a lower percentage of saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) than milk from ruminants (Figure 3). The percentage of unsaturated fatty acids in milk from mares, donkeys, and women is similar and greater than that of milk from ruminants. This high degree of unsaturation is mainly caused by a greater content of polyunsaturated fatty acids (PUFA) with intermediate and high numbers of carbon atoms and could represent a nutritional advantage (Solaroli et al., 1993).

The range of fatty acid profiles reported in the literature (Doreau and Martin-Rosset, 2002; Jensen et al, 1990; Malacarne et al., 2002; Park et al., 2007; Gastaldi et al., 2010; Uniacke-Lowe, 2011) is presented in Table 2. Regarding the PUFA amount, the highest value was found in mares' milk (up to 51 %), followed by donkeys (to 30 %), and women (to 19%). The lowest values (on average less than 5 %) are observed in milk from ruminants (with lowest amount observed in buffalos' milk). The amount of C-18:2 and C-18:3 are greater in

milk from non-ruminants compared to ruminants. The fatty acids of milk from mares and donkeys are mainly unsaturated or short-chained (Gastaldi et al., 2010). This could be interesting from a nutritional point of view. In addition to this characteristic of milk from non-ruminants, Salamon et al. (2009) reported that milk from mares and donkeys had greater concentrations of linoleic (C-18:2, ω -6) and α -linolenic acid (C-18:3, ω -3) compared to milk from ruminants; 5 and 224 times more, respectively.

The observed differences in milk fatty acid composition were partly driven by differences in feed, but mainly due to differences in the mechanisms of fatty acid synthesis. The milk fat composition of non-ruminants were mainly conditioned by the composition of dietary lipids, while in ruminants, before absorption, fatty acids from the feed are hydrogenated to SFA by ruminal microbes (Jahreis et al., 1999 and Korhonen, 2009). The same authors reported that during that biohydrogenation process, the formation of *trans* fatty acids (vaccenic, C-18:1 11t; and rumenic acid, C-18:2 9c, 11t; an isomer of the conjugated linoleic acids (CLA) occur.

German and Dillard (2006) and Uniacke-Lowe (2011) reported that CLA isomers might cause lowered risk of cardiovascular diseases, carcinogenesis, diabetes and osteoporosis as well as modulating the immune system. The presence of

Table 2. Fatty acids profile of different species - interval values (minimum and maximum) reported in literature (Doreau and Martin-Rosset, 2002; Jensen et al, 1990; Malacarne et al., 2002; Park et al., 2007; Gastaldi et al., 2010; Uniacke-Lowe, 2011)

Milk	SFA (%*)	MUFA (%*)	PUFA (%*)	C - 18:2 (%*)	C - 18:3 (%*)	CLA (%*)
Woman	36-45	33-45	8-19	6.0-17.7	0.6-3.4	0.2-1.1
Mare	37-55	18-36	13-51	3.6-20.3	2.2-31.2	0.02-0.1
Donkey	46-68	15-35	14-30	6-15.2	4-16.3	trace
Buffalo	62-74	24-29	2.3-3.9	2.0	0.2-1.4	0.4-1
Cow	55-73	22-30	2.4-6.3	1.2-3.0	0.3-1.8	0.2-2.4
Goat	59-74	22-36	2.6-5.6	1.9-4.3	0.3-1.2	0.3-1.2
Ewe	57-75	23-39	2.5-7.3	1.6-3.6	0.5-2.3	0.6-1.1

*% of total fatty acids

trans fatty acids in mares' milk implies some fatty acid hydrogenation by intestinal microorganisms before absorption. In addition, according to Stender et al. (2008) non-ruminants and women are also able to convert vaccenic acid into rumenic acid, but to a far lesser extent than ruminants.

The amount of cholesterol in ruminants' milk (13.1-31.4 mg/100 mL from cows, 14-29.0 mg/100 mL from ewes, 10.7-18.1 mg/100 mL from goats, and 4-18.0 mg/100 mL from buffalos) was similar to milk from women (14-20 mg/100 mL; Jahreis et al., 1999; Malacarne et al., 2002; Park, 2009; Gastaldi et al., 2010; Uniacke-Lowe, 2011; Devle et al., 2012). The established content of cholesterol in milk from non-ruminants appears to be much lower (5.0-8.8 mg/100 mL from mares and trace amounts from donkeys). The cholesterol is, from one point of view, an essential and inevitable component of body cell membranes as well as of the central nervous system (Gidding et al., 2006). On the other hand, it is frequently associated with cardiovascular diseases.

Conclusions

Variability in milk composition is a result of genetic, physiological, nutritional, and environmental factors. Regarding the overall milk composition, remarkable differences among energy value, fat, lactose, protein and ash content were found when various milk species were compared. However, there were also some similarities among milk from ruminants (cow, buffalo, goat and ewe) and non-ruminants (mare, donkey). The structure of fat globule membranes, which significantly affects fat digestibility, contains similarities among milk from non-ruminants and women, while the same structure differs significantly in ruminants. The size of fat globules, which also affects fat digestibility, differs significantly among species and is highly correlated to the milk fat content. The amount of triacylglycerols was notably higher in milk from ruminants and women compared to milk from mares and donkeys, while the amounts of free fatty acids and phospholipids were notably lower. The triacylglycerol structure, affecting fat absorption, was found to be similar in milk from women and non-ruminants.

The saturated fatty acids (SFA) and monounsaturated fatty acids (MUFA) were lower in milk from non-ruminants compared to that of ruminants, while the percentage of unsaturated fatty acids was higher. The amount of C-18:2 and C-18:3 were remarkably higher in milk of non-ruminants in comparison to ruminants. The cholesterol content was similar in milk from ruminants and women. However, cholesterol in milk from non-ruminants was notably lower.

Collectively, the overall milk composition, fat globule structure, and digestibility, suggests that milk from non-ruminants milk might be more suitable source of human nourishment than milk from ruminants.

Ukupni sastav i sastav masti u mlijeku različitih vrsta

Sažetak

Mlijeko kao esencijalni izvor hrane za mladunčad značajno se razlikuje ovisno o vrsti. U ljudskoj prehrani svježje mlijeko i prerađevine predstavljaju važan izvor bjelančevina, masti i energije. Kravlje mlijeko dominira u svjetskoj proizvodnji sa 85 % ukupne proizvodnje mlijeka, a slijede ga mlijeko bivola, koza, ovaca, kobilica te magarica. Vezano uz konzumaciju mlijeka problemi se mogu javiti u dojenčadi i to kao alergija na proteine mlijeka. Cilj ovoga rada bio je dati pregled ukupnog sastava mlijeka te sastava i karakteristika masti u mlijeku različitih životinjskih vrsta u odnosu na majčino mlijeko. S obzirom na ukupni sastav mlijeka utvrđene su značajne razlike između uspoređivanih mlijeka u pogledu energetske vrijednosti, sadržaja masti, laktoze, bjelančevina te pepela, dok su sličnosti utvrđene unutar preživača i nepreživača. Utvrđeno je da je struktura membrana i veličina globula masti slična u mlijeku nepreživača i majčinom, dok se ista u mlijeku preživača značajno razlikuje. Značajno više vrijednosti triglicerida te značajno niže vrijednosti slobodnih masnih kiselina i fosfolipida utvrđene su u majčinom mlijeku i mlijeku preživača u usporedbi s mlijekom magarice i kobile. Glede strukture triglicerida, sličnosti su utvrđene između majčinog mlijeka i mlijeka nepreživača. Mlijeko nepreživača karakterizira niži sadržaj zasićenih i mononezasićenih te viši sadržaj nezasićenih masnih

kiselina, osobito C-18:2 i C-18:3 u odnosu na mlijeko preživača. Glede udjela kolesterola, u mlijeku preživača utvrđene su slične vrijednosti kao i u majčinom mlijeku, dok je u mlijeku nepreživača razina kolesterola značajno niža. Uzimajući u obzir sve navedene karakteristike ukupnog sastava mlijeka te sastava masti u mlijeku, kao i strukturu i probavljivost globula masti, može se pretpostaviti da je mlijeko nepreživača pogodnije za ljudsku prehranu u odnosu na mlijeko preživača.

Ključne riječi: vrste sisavaca, ukupni sastav mlijeka, sastav masti u mlijeku

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