Whole Goat Milk Formula

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Whole goat milk can be used as a source of protein, fat and lactose to manufacture infant, follow-on and young child formulas. The use of whole goat milk without adjustment of the whey:casein ratio results in a formula with an average of 50% of its lipids from goat milk fat, supplying palmitic acid (including at the sn-2 position), short and medium chain fatty acids, milk fat globule membrane and cholesterol.

Keywords: whole goat milk ; infant formula ; milk fat ; infant nutrition

1. Breast Milk and Breast Milk Substitutes

Human breastmilk is the optimal source of nutrition for the human infant. While it is recommended to exclusively breastfeed to 6 months of age [1], infant formulas are the most suitable breast milk substitutes when breastfeeding is not possible. Cow milk ingredients have traditionally been used as the source of proteins in the manufacture of infant, follow-on and young child formulas. The main source of lipids in formulas is commonly a blend of vegetable oils, and lactose, vitamins and minerals are added to match the macro- and micronutrient composition of human milk as outlined in local regulations [2][3]. While whole cow milk can be used in the formulation of infant formulas, it is more common to use skim milk and whey protein powdered ingredients to reach a whey:casein ratio of 60:40, as in mature human milk, while providing an adequate amino acid supply within the allowed protein levels in the regulations [4]. However, the whey protein adjustment limits the amount of milk fat in the final infant formula. Other sources of cow milk fat could be added such as liquid or powdered cream and anhydrous milk fat, but these ingredients are usually costly or not available in paediatric grade [3].

Human milk lipids are present as milk fat globules with a complex structure of triglyceride droplets stabilized by a trilayered membrane, the milk fat globule membrane (MFGM) [5]. Human milk fat has a unique fatty acid profile, with a high level of palmitic acid [6]. To match the palmitic acid concentration of human milk, infant formula manufacturers need to add unmodified or structured palm oil or milk fat [2][3]. In the last decade, there has been increased criticism over the use of palm-derived products and a push from consumers to limit the use of such ingredients [7]. In addition, vegetable oils, and in particular palm oil, contain some contaminants such as 2- and 3-monochloropropane-1,2-diols and their fatty acid esters formed during the oil refining process [8]. This has led to a resurgence in the use of milk fat for infant formula products, particularly in Europe [3].

2. Infant Formula Made from Goat Milk

While the use of animal milk to feed infants has a long tradition, infant formula products are usually based on cow milk ingredients or plant-based ingredients, e.g., soy or rice protein isolate as a source of proteins and maltodextrin or other sugars as a source of carbohydrates [2]. Due to increased consumer demand for alternatives to cow milk [9] and the recognition of the presence of anti-nutritional factors, such as trypsin inhibitor and phytate, phytoestrogens and undesirable taste in plant-based products [10][11], goat milk has been reintroduced in pediatric nutritional products in the last 30 years. Goat milk is perceived to be easier to digest than cow milk, making it beneficial for infant nutrition [12][13][14]. Milk from goats with a low α_{s1}-casein genotype is favoured for manufacture of infant formulas, as α_{s1}-casein is a predominant milk allergen [15] and the milk forms a softer curd in acidic environment such as in the stomach [16][17]. Other factors such as nutritive value (absence of A1 β-casein in goat milk [18]) and an association with tradition [19][20] make goat milk more attractive to some consumers.

As with traditional infant formulas based on cow milk protein ingredients, some formulas based on goat milk are whey-adjusted, i.e., using goat skim milk and whey protein ingredients to reach a whey:casein ratio of 60:40 and therefore using mainly vegetable oils as the source of lipids [14]. This review will focus on the infant, follow-on and young child formulas based on whole goat milk without adjustment of the whey:casein ratio (i.e., maintaining the natural 20:80 whey:casein

ratio of whole goat milk) and with clinical evidence that it supports healthy growth and development of the infant [21][22][23]. The use of whole goat milk has two main advantages, it allows to match more closely the diverse composition of human milk fat but also its complex structure.

3. Whole Goat Milk Fat to Supply a Variety of Fatty Acids and *sn*-2 Palmitate

The α_{s1}-casein genotype has an impact on the fatty acid profile of goat milk, with the low α_{s1}-casein genotypes associated with increased level of unsaturated fatty acids [24]. Goat milk and cow milk have a relatively comparable total fat content and fatty acid profile [25][26]. SCFAs, in particular C4:0, are not always detectable or reported for human milk (Table 1), however a few studies have reported levels of C4:0 in lower concentrations than in cow and goat milk fat ([27][28]; Table 1). Fat from goat milk contains a higher amount (15%–18%) of the MCFAs C6:0, C8:0 and C10:0 compared to cow milk (5%–9%) [26]. As MCFAs are more readily released and absorbed in the gastrointestinal tract (GIT), this unique composition may contribute to a greater digestibility of goat milk fat compared to cow milk fat [26]. Cow milk contains on average slightly more palmitic acid than goat milk (Table 1).

Table 1. Fatty acid concentration (% of total fatty acids) in human milk, cow milk, goat milk and whole goat milk-based infant formula.

	Human Milk [1] Europe	Human Milk [1] Asia	Cow Milk [2]	Goat Milk [2]	Whole Goat Milk-Based IF [3] 48% MF	Whole Goat Milk-Based IF [4] 55% MF	Cow Milk-Based IF Vegetable Oil Only [6]	Cow Milk-Based IF MF [1]
Butyric acid C4:0	ND	ND	3.2–3.3	2.0–2.6	1.17	3.1	ND	2.4
Caproic acid C6:0	0.39	0.07	1.6–2.1	2.4–2.9	1.06	2.5	ND/0.2	1.3
Caprylic acid C8:0	0.19 (0.09–0.24)	0.17 (0.11–0.28)	1.2–1.3	2.7–2.7	1.11	2.0	1.2/2.5	1.7
Capric acid C10:0	1.29 (0.83–1.63)	1.31 (0.52–2.48)	3.0–3.1	8.4–9.7	3.43	7.3	1.1/1.8	2.2
Lauric acid C12:0	5.98 (4.15–8.33)	5.56 (2.97–13.82)	3.1–3.3	3.3–4.3	1.54	4.2	5.4/13.4	6.3
Myristic acid C14:0	6.44 (4.98–9.38)	5.70 (3.50–12.12)	9.5–12.1	9.6–10.3	3.68	7.0	4.6/5.2	7.2
Myristoleic acid C14:1	0.18	0.26 (0.09–1.11)	0.7–1.1	0.09–0.16	0.12	ND	ND/ND	0.8
Pentadecanoic acid C15:0	0.25 (0.16–0.32)	0.20 (0.08–0.50)	ND	ND	0.35	0.6	ND/ND	0.6
Palmitic acid C16:0	21.99 (15.43–25.62)	21.78 (17.55–29.00)	26.5–32.2	24.6–27.7	12.30	17.0	26.3/7.7	18.9

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Palmitoleic acid C16:1 *n-7*	1.98 (1.65–2.31)	2.44 (1.29–4.59)	ND	ND	0.39	ND	0.6/0.1	1.1
Heptadecanoic acid C17:0	0.29 (0.22–0.33)	0.28 (0.10–0.41)	ND	ND	0.29	0.4	ND/ND	0.3
Stearic acid C18:0	7.37 (5.58–9.32)	5.58 (3.90–6.79)	8.9–14.6	9.7–12.9	5.89	6.3	5.3/3.2	6.7
Oleic acid C18:1 *n-9*	36.30 (28.93–41.69)	30.80 (21.85–36.96)	19.3–24.1	19.4–24.0	40.65	31.0	37.6/43.3	28.1
Linoleic acid C18:2 *n-6*	13.99 (10.16–16.59)	16.90 (7.53–24.20)	ND	ND	10.79	14.0	14.0/20.5	16.7
Conjugated linoleic acid C18:2 c9, t11	0.27–0.49 [3]	ND	0.1–1.9	0.4–3.7	0.33	ND	ND/ND	ND
α-linolenic acid C18:3 *n-3*	0.76 (0.45–1.05)	1.40 (0.35–4.06)	ND	ND	1.58	1.2	1.6/1.8	1.5
Arachidic acid C20:0	0.21 (0.14–0.31)	0.32 (0.03–2.07)	ND	ND	0.24	0.3	ND/0.3	0.3
Arachidonic acid C20:4 *n-6*	0.47 (0.37–0.64)	0.64 (0.30–2.57)	ND	ND	0.45	ND	0.3/0.3	ND
Eicosapentaenoic acid C20:5 *n-3*	0.09 (0.05–0.13)	0.31 (0.07–1.59)	ND	ND	0.12	ND	ND/0.0	ND
Behenic acid C22:0	0.09 (0.05–0.13)	0.08 (0.05–0.14)	ND	ND	0.33	ND	ND/0.4	0.1
Docosahexaenoic acid C22:6 *n-3*	0.28 (0.18–0.42)	0.55 (0.19–1.13)	ND	ND	0.44	ND	0.2/0.3	ND
Tetracosanoic acid C24:0	0.07 (0.03–0.16)	0.07 (0.01–0.14)	ND	ND	0.21	ND	ND/0.1	ND

[1] from [3]. [2] from [26]. [3] Measured using gas chromatography (n = 2). [4] from [25]. [5] from [29]. [6] from [3]; values (%/%) are for cow milk-based IF manufactured with a blend of vegetable oils with palm oil/without palm oil. ND: not determined. IF: infant formula. MF: milk fat.

Human milk has more oleic, docosahexaenoic (DHA), arachidonic acid (ARA), linoleic and α-linoleic acids than goat or cow milk (Table 1). Hence, it is not possible to use goat or cow milk fat as the only source of lipids for infant formulas. Therefore, vegetable oils and oils rich in DHA and ARA must be added to match the fatty acid profile of human milk. The fatty acid profile of two examples of infant formulas made from whole goat milk, one with a 48% and one with 55% of lipids as milk fat, is given in Table 1. By using a combination of vegetable oils and milk fat from whole goat milk, levels of unsaturated fatty acids comparable to human milk can be achieved. Most importantly the use of milk fat in infant formula provides a more complex fatty acid profile similar to that found in human milk (Table 1), with increased levels of short and

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medium chain fatty acids (SCFAs and MCFAs, respectively), presence of fatty acids typical of milk fat such as C15:0, C16:1 *n7*, C17:0, conjugated linoleic acid (CLA) and branched-chain fatty acids (BCFAs), and comparable levels of palmitic acid. A similar compositional effect can be obtained by using milk fat from cow milk-derived ingredients to manufacture cow milk-based infant formulas (Table 1). Indeed, more common cow milk-based infant formulas are manufactured using skim milk and whey protein powders blended with vegetable oils with or without palm oil. As the lipid composition of infant formulas is influenced by the source of vegetable oils and the type of dairy ingredients used in the formulation, the fatty acid profile of three cow milk-based infant formulas is given for comparison in Table 1.

Early reports indicate that goat milk contains 280 mg β-keto acids/kg of fat, in particular those of 16 and 18 carbon chain length [30]. In addition, lipid absorption and β-oxidation of dietary MCFAs result in the release of ketones, a source of energy and acetyl-CoA for the brain of the growing infants [31]. Breastfed infants have higher levels of plasma ketones than formula-fed infants [32]. Thus, an infant formula made from whole goat milk provides a source of MCFAs and β-keto acids, which may contribute to brain development. In addition, goat milk contains BCFAs, such as 4-methyl- and 4-ethyl-octanoic acid [32]. BCFAs are also found in human milk and their concentration is influenced by maternal diet [33]. BCFAs are essential to bacterial membrane functions and have been shown in limited animal and human studies to alter the gut microbiota [33]. CLA (*c*9, *t*11) levels in goat milk and infant formula based on whole goat milk are within the same range as found in human milk (Table1). A study looking at CLA levels in human milk and a range of cow milk-based formulas found that human milk contained significantly more CLA and some infant formulas did not contain any detectable levels [34]. While CLA is considered an anticarcinogen, its role in infant nutrition remains unclear.

As seen in Table 1, both goat milk and cow milk are good sources of palmitic acid. The use of vegetable oils as the only source of lipids in infant formulas results in levels of palmitic acid below (7.7%), when palm oil is not used, or similar (26.3%), when palm oil is used, to that of human milk (15.4%–29.0%) (Table 1). Depending on the level of milk fat used, the use of whole goat milk as a source of milk fat in infant formula results in infant formulas with a level (12.3%–17.0%) of palmitic acid close to the lower end of the concentration in human milk (15.4%–29.0%) (Table 1). Similarly the use of cow milk fat in infant formulas results in comparable levels of palmitic acid (Table 1).

Human milk is quite unique in the way that up to 70% of its palmitic acid is found in the *sn*-2 position of the triglyceride molecules [6]. Reports on the *sn*-2 palmitic acid content in human milk (Table 2) vary in the literature partly due to different analytical methods used but the *sn*-2 palmitic acid content does not seem affected by maternal diet or geographical location [31]. Palm oil is commonly added in infant formulas to reach a palmitic acid level within the range found in human milk (Table 1). However most of the palmitic acid in palm oil is in the *sn*-1,3 position, unless it has been enzymatically or chemically interesterified to result in structured palm oil rich in 1,3-dioleyl-2-palmitoylglycerol, also called OPO or Betapol [7]. Cow milk-based infant formulas have therefore a variable *sn*-2 palmitic acid content depending on the type of added vegetable oils (Table 2). Goat milk and cow milk are natural sources of *sn*-2 palmitic acid (Table 2). By using whole goat milk without modification of the whey:casein ratio, an infant formula can contain up to 31% of palmitic acid in the *sn*-2 position, so about half the level in human milk (Table 2), but more than the level in infant formulas (as low as 8%) manufactured with vegetable oils only [2]. The advantage of the stereospecifity of palmitic acid for infant nutrition, beyond mimicking the triglyceride structure of human milk fat, will be discussed later.

Table 2. *sn*-2 palmitic acid percentage in human milk, cow milk, goat milk and whole goat milk-based infant formula.

	Human Milk [1,2]	**Cow Milk [2,3]**	**Goat Milk [3]**	**Whole Goat Milk-Based IF [4] 48% MF**	**Whole Goat Milk-Based IF [3] 55% MF**	**Cow Milk-Based IF Vegetable Oils Only [2]**
% *sn*-2 palmitic acid	51–88	37–45	35	29.5	31	10–20/39–47 [5]

[1] from [6][35]. [2] from [3]. [3] from [25]. [4] Measured with ISO 6800 by ITERG, France (n = 6). [5] Values (%/%) are given for cow milk-based IF manufactured with a blend of vegetable oils without structured palm oil/with structured palm oil. IF: infant formula; MF: milk fat.

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