Review

Raw or heated cow milk consumption: Review of risks and benefits

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\textbf{Abstract}

In the context of the prevailing trend toward more natural products, there seems to be an increasing preference for raw milk consumption as raw milk is associated with several perceived health benefits that are believed to be destroyed upon heating. However, many human pathogens can be isolated from raw cow milk. The prevalence of foodborne pathogens in raw cow milk varies, but their presence has been demonstrated in many surveys and foodborne infections have been repeatedly reported for \textit{Campylobacter}, \textit{Salmonella} spp. and human pathogenic verocytotoxin-producing \textit{Escherichia coli}. In industrialized countries, milk-borne and milk product-borne outbreaks represent 2–6\% of the bacterial foodborne outbreaks.

The aim of this review is to present scientifically sound data regarding the risks and benefits related to the consumption of raw and heated cow milk. Both microbiological aspects (e.g., the prevalence of milk-borne pathogens, pathogen growth inhibition by antimicrobial systems and by lactic acid producing bacteria, probiotic bacteria, etc.) and nutritional or health aspects (nutritional value, immunity, allergies, lactose intolerance, diabetes, milk digestibility, etc.) are considered.

As such, it is demonstrated that consumption of raw milk poses a realistic health threat due to a possible contamination with human pathogens. It is therefore strongly recommended that milk should be heated before consumption. With the exception of an altered organoleptic profile, heating (in particularly ultra high temperature and similar treatments) will not substantially change the nutritional value of raw milk or other benefits associated with raw milk consumption.

1. Introduction

The consumption of raw milk is not well-documented, but in the context of the current trend toward “consuming natural” and “purchasing locally”, raw milk consumption is becoming more popular. This is nourished by the perception that heating destroys the nutritional and health benefits of milk, and can even induce some detrimental effects. However, due to its high nutritional value together with the neutral pH and high water activity, raw milk serves as an excellent growth medium for different microorganisms, whose multiplication depends mainly on temperature and on competing micro-organisms and their metabolic products. In order to guarantee its microbial safety and to prolong its shelf-life, milk is heat treated.

The impact of milk pasteurization on public health can be clearly illustrated by means of historical data. Before 1938, an estimated 25\% of all foodborne and waterborne disease outbreaks in the US were associated with milk, whereas nowadays, the percentage of such outbreaks associated with milk is estimated to be below 1\% (\textit{FDA}, 2011). Between 1880 and 1907, 29 milk-borne outbreaks...
were reported on average each year in the US. With the adoption of pasteurization in 1938, milk-borne diseases dropped to only 46 outbreaks during the 19-year period from 1973 to 1992, corresponding to an average of 2.4 outbreaks each year (Headrick et al., 1998). A recent report of the U.S. Centers for Disease Control and Prevention (CDC) indicates that the vast majority of milk-borne outbreaks in the US are in states that permit the sale of raw milk (Langer et al., 2012). In England and Wales, the great majority of milk-borne outbreaks during the eighties were attributed to the consumption of raw milk. In Scotland, a similar situation existed until the sale of unpasteurized milk was prohibited in 1983, which led to a significant drop in the incidence of doses related to liquid milk consumption (Barrett, 1986; Burt & Wellstead, 1991; Galbraith, Forbes, & Clifford, 1982). In the mid-twentieth century, the main illnesses associated with raw milk consumption were brucellosis and tuberculosis. These have been eradicated as milk-borne diseases in developed countries, mainly through herd certification programs which included culling of infected animals, the installation of refrigerated bulk tanks for milk collection on farms and the introduction of pasteurization (Griffiths, 2010; Lejeune & Rajala-Schultz, 2009). In the past, pasteurization conditions were standardized based on the destruction of Mycobacterium tuberculosis, a relatively heat-resistant non-sporeforming bacterium that formerly was among the most serious pathogenic bacteria present in milk (Walstra, Geurts, Noomen, Jellema, & Van Boekel, 1999). Pasteurization standards today are based upon the destruction of Coxiella burnetii, the most heat-resistant milk-borne zoonotic pathogen known (Stabel et al., 2001). In the past 30 years, several previously unrecognized foodborne bacterial infections, including infection with Campylobacter jejuni, Listeria monocytogenes, and Escherichia coli strain O157 (or more general verocytotoxin-producing pathogenic E. coli), have emerged as significant causes of human morbidity and mortality (Lejeune & Rajala-Schultz, 2009). Pathogens mainly present in raw milk today are, e.g. C. jejuni, Salmonella spp., Staphylococcus aureus, L. monocytogenes, pathogenic E. coli and Yersinia enterocolitica (Speer, 1998; Walstra et al., 1999).

In Europe, the current regulatory microbial criteria for raw cow milk are ≤100 000 cfu/ml for plate count (at 30 °C) and ≤400 000 cfu/ml for somatic cells, as is stipulated in Regulation (EC) 853/2004 laying down specific hygiene rules on the hygiene of foodstuffs. In this Regulation, health requirements for production animals and hygienic requirements on milk production holdings (e.g. regarding premises and equipment, hygiene during milking, collection and transport, staff hygiene) are established as well. In general, raw milk intended for human consumption must meet the requirements of the General Food Law (Regulation (EC) 178/2002) and be free of pathogens. Even though improvements in hygiene resulted in routine production of raw cow milk with less than 20 000 cfu (total flora)/ml (De Reu, Grijspeerdt, & Herman, 2004), this does not guarantee raw milk to be free of pathogens. In ~1–6% of the human outbreaks reported in developed countries, milk has been identified as the vehicle of infection (De Buyser, Dufour, Maire, & Lafarge, 2001; EFSA, 2010; Gillespie, Adak, O’Brien, & Bolton, 2003; Headrick et al., 1998; Lee & Middleton, 2003). An overview of foodborne disease reports from different industrialized countries indicates that milk and milk products are implicated in a range of factors, such as pasteurization or consumption of raw cow milk and both outside Europe (Table 2); no human cases/outbreaks were reported in relation to entero-toxins of S. aureus in raw cow milk. The growth of both pathogens is limited in raw milk by the commensal flora present, whereas listeriosis is characterized by a relatively high infectious dose and S. aureus requires a high number in order to produce enterotoxins at an amount dangerous to humans. Both pathogens are however reported as sources of food poisoning when raw milk was used in food preparations or dishes, such as mashed potatoes that were insufficiently cooked (Jørgensen et al., 2005). Such risks and related to deficiencies in the pasteurization process or to a post-pasteurization contamination, e.g. due to faulty equipment, poor hygiene and/or human error (CDC, 2008; Dalton et al., 1997; De Buyser et al., 2001; Fleming et al., 1985; Schuchat, Swaminathan, & Broome, 1991), are not considered in this study. The number of raw cow milk-borne outbreaks described for Streptococcus equi subsp. zooepidemicus, Arcanobacter pyogenes and tick-borne encephalitis virus are very rare (Barrett, 1986; Vereta et al., 1991).

Regarding the public health impact, the development of a disease after consuming (contaminated) raw milk depends on a range of factors, such as the pathogenicity of the microorganism (or the toxicity of the toxin), the number of ingested microorganisms (or quantity of toxins), the human infective dose, and the health status of the consumer (D’August, 1989; Lund & O’Brien, 2011). People most at risk are the very young, elderly persons, pregnant women and immune-compromised persons (YOPs), although anyone can be affected, including healthy young adults.
The presence of pathogens in raw cow milk is estimated for Campylobacter spp. and Salmonella spp., human pathogenic E. coli and L. monocytogenes, based on data indicating their occurrence in raw milk or on dairy cattle farm. Hereto, the opinion of several experts was collected and individual Belgian lab results and available research data were considered, since there are at present no Belgian monitoring campaigns to estimate the prevalence of these pathogens in the cattle population. Nevertheless, the same data and evaluation can be used for assessing the situation in other European countries, as the same regulation, standards and hygienic requirements apply for all European member states. The expert opinion was confirmed by the data collected at European level on the prevalence of the pathogens in raw cow milk (Table 2).

With respect to the presence of Campylobacter spp., Salmonella spp., human pathogenic E. coli and L. monocytogenes in raw cow milk, no statistically based European prevalence data are available. Because regulations, management and pathogen pressure from the environment and from the animals differ substantially between countries over the world, it was decided to limit this review study to European countries for which at least the regulation is the same.

### Table 1
List of human pathogenic micro-organisms potentially present in raw cow milk and sources of contamination.

<table>
<thead>
<tr>
<th>Pathogenic bacteria</th>
<th>Direct passage from the blood into the milk (systemic infection)</th>
<th>Mastitis (udder infection)</th>
<th>Faecal contamination (external contamination of the milk during or after milking)/contamination from skin</th>
<th>Environmental sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salmonella spp.</strong></td>
<td>(x) (S. Dublin)</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Brucella abortus</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Mycobacterium bovis</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Coxiella burnetii</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Mycoplasma avium subsp. paratuberculosis</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Listeria monocytogenes</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Campylobacter coli and jejuni</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Corynebacterium pseudotuberculosis</strong></td>
<td>(x)</td>
<td>(x)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Human pathogenic Yersinia</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Bacillus cereus</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Enterotoxin producing Staphylococcus aureus</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Arcanobacter pyogenes</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Streptococcus zooepidemicus</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td><strong>Leptospira</strong></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x (Urine)</td>
</tr>
</tbody>
</table>

### Pathogenic viruses

| Rift valley fever virus | x |
| Viruses of the tick-borne encephalitis (TBE) complex | x |

### Pathogenic parasites

| Cryptosporidium parvum | x |

### Microbial toxins

| Type B toxins of Clostridium botulinum | x (Toxins) | x (Spores) | x (Spores) |

(x) Rarely.

| Potentially zoonotic. |
| Only certain strains of E. coli that are transferred by cattle, which contain a human—virulent combination of virulence factors and that are pathogenic to humans. Strains of the serotype O157:H7 are the most frequently reported, but strains of other serotypes can result in human cases as well (e.g. O26, O91, O103, O111, O121 and O145). |
| Y. enterocolitica and Y. pseudotuberculosis (Shwimmer et al., 2007). Only Y. enterocolitica biotypes 1b, 2, 3, 4 and 5 of are pathogenic to humans. |
| Only Y. pseudotuberculosis. |
| Diarrheal toxins from B. cereus could be produced in raw milk. B. cereus can also produce emetic toxins (cereulide), but they were never found in milk. |

### Table 2
Evaluation of the relative microbial risk associated with raw milk consumption.

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Presence in dairy cattle farms in Belgiuma</th>
<th>Presence in raw cow milk in Europeb</th>
<th>Indication of number of outbreaks after raw cow milk consumption in Europe and worldwidec</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Salmonella spp.</strong></td>
<td>Present</td>
<td>0–2.9%</td>
<td>5 (Europe) or 39 (world)</td>
</tr>
<tr>
<td><strong>Campylobacter jejuni and coli</strong></td>
<td>Present</td>
<td>0–6%</td>
<td>18 (Europe) or 39 (world)</td>
</tr>
<tr>
<td><strong>Human pathogenic E. coli</strong></td>
<td>Present</td>
<td>0–5.7%</td>
<td>13 (Europe) or 28 (world)</td>
</tr>
<tr>
<td><strong>Listeria monocytogenes</strong></td>
<td>Present</td>
<td>2.2–10.2%</td>
<td>0 (Europe) or 2 (world)</td>
</tr>
</tbody>
</table>

a Based on individual lab results and available research projects. In a recent study, a between-herd seroprevalence of 3.3% (1.51–5.09) was estimated based on Salmonella antibodies detected in bulk tank samples in the North of Belgium (Ribbens et al., 2010).
b Based on punctual studies reporting the frequency.
c Human outbreaks reported in literature between 1970 and 2010.
d Outliers: 0–0.6% (Switzerland, Bachmann & Spahr, 1995; Stephan & Bühler, 2002) and 45% (Spain, Domínguez Rodriguez et al., 1985).
e L. monocytogenes is frequently detected in raw milk, but its significance in terms of outbreaks due to raw cow milk consumption is very low.
Based on punctual studies reported in literature, the frequency of these pathogens occurring in raw milk can be estimated. The detection frequency of pathogenic bacteria in bulk tank milk varies among surveys and may be related to geographic (environmental) differences, season, farm size, density of animal populations, and regional differences in management and husbandry of dairy cattle, variation in sampling and types of samples evaluated, differences in detection methodologies used, etc. (Oliver et al., 2005). Regarding the occurrence of C. jejuni, a frequency between 0 and 6% is reported in Europe for raw cow milk (Beumer, Cruysen, & Birtantie, 1988; Humphrey & Hart, 1988; Oosterom, Engels, Peters, & Pot, 1982). The frequency of Salmonella spp. in tank milk is often nil to very low; most studies report frequencies below 1% (EFSA, 2010; De Louvois & Rampling, 1998; De Reu et al., 2004; Desmasures, Bazin, & Guéguen, 1997; Hahn, Walte, Coenen, & Teufel, 1999; Humphrey & Hart, 1988; Rea, Cogan, & Tobin, 1992; Stephan & Bühler, 2002). The frequencies estimated for human pathogenic verocytotoxigenic E. coli in milk are in Europe situated between 0 and 5.7% (Coia, Johnston, Steers, & Hanson, 2001; Colombo, Pacciarini, & Fusi, 1998; Heuvelink et al., 1998; Massa, Goffredo, Altieri, & Natola, 1995; McKee, Madden, & Gilmour, 2003; Mechie, Chapman, & Siddons, 1997; Messe lhäuser, Beck, Gallien, Schalch, & Busch, 2008; Murphy et al., 2007; Raynaud et al., 2006; Schouten et al., 2005; Solomakos et al., 2009; Stephan & Bühler, 2001). With respect to the E. coli serotype O157:H7, recent studies in different countries affirm its frequency of occurrence to be very low in milk, with a value between 0% and 2%, depending on the cultivation method used (EFSA, 2009a, 2010). There are no validated standard methods for isolating pathogenic E. coli of other serotypes such as O26, O91, O111 en O11, rendering the estimation of the prevalence of these serotypes difficult (Vernoy-Rozand & Rozé, 2003). The frequency of L. monocytogenes in raw cow milk can vary broadly, from 0% (Stephan & Bühler, 2002) to 45% (Domínguez Rodriguez, Fernández Garayzabal, Vazquez Boland, Rodriguez Ferri, & Suarez Fernández, 1985), but most of the reported frequencies are situated between 0 and 10% (Bachmann & Spahr, 1995; De Reu et al., 2004; Fenlon, Stewart, & Donachie, 1989; Greenwood, Roberts, & Burden, 1991; Hahn et al., 1999; Harvey & Gilmour, 1992; Jouve & Lahellec, 1991; Meyer-Broseta, Diet, Bastian, Rivi ère, & Cerf, 2003; Rea et al., 1992; Rodler & Körbler, 1989; Sanaa, 1993; Waak, Tham, & Danielsson-Tham, 2002).

These surveys clearly demonstrate that raw cow milk can be a source of foodborne pathogens of human health significance, with Salmonella, C. jejuni/coli and human pathogenic verocytotoxigenic E. coli being the main bacteria that may be transferred from raw milk to humans. Considering the data combined in Table 2 it is clear that the risk for (Belgian) consumers can be considered real, and even high in case raw milk would be frequently consumed.

2.2. Effect of heating milk on pathogens potentially present

The risk posed by raw milk consumption is considerably reduced and even eliminated by a heat treatment. Based on the temperature time conditions applied, different heat treatments can be distinguished, such as thermization, pasteurization and sterilization, including UHT (ultra high temperature) and ISI (innovative steam injection) treatment, aimed at different microbial targets and resulting in a different shelf-life of the milk. Thermization (57–68 °C/15–20 s), which is mainly a pre-treatment performed for technological reasons only to extend the shelf-life of refrigerated milk, results in a 3–4 log reduction of the vegetative commensal flora (e.g. Micrococcus, coliforms, Pseudomonas, Flavobacterium, Enterobacter, Aeromonas, Alcaligenes, etc.), but does not guarantee the inactivation of all vegetative pathogens. Properly applied pasteurization (e.g. 71–74 °C/15–40 s for “high temperature short time” or HTST pasteurization) eliminates all vegetative micro-organisms present in milk (i.e. their probability to survive is reduced with a factor of 10⁶), including vegetative pathogens such as human pathogenic verocytotoxigenic E. coli, Salmonella spp., L. monocytogenes, Y. enterocolitica, C. jejuni/coli, enterotoxin producing S. aureus and vegetative Clostridium botulinum. Already formed and heat-resistant enterotoxins of S. and C. botulinum B toxin as well as the emetic toxins (cereulide) of Bacillus cereus are not destroyed by pasteurization. Pasteurization neither destroys the heat-resistant spores of C. botulinum nor of B. cereus. On the contrary, pasteurization may induce the germination of these spores, which subsequently are able to grow and produce toxins during the preservation of pasteurized milk.

Sterilization (110–120 °C/10–20 min), UHT (135–140 °C/6–10 s for indirect and 140–150 °C/2–4 s for direct UHT) or ISI (150–200 °C < 0.1 s) treatment destroys vegetative as well as most sporulating pathogens (including spores of C. botulinum and B. cereus, but with the exception of spores from some non-pathogenic very thermoresistant bacilli like Bacillus thermodurans), therefore offering in most cases a so-called commercially sterile product (minimum a log reduction of 12). Toxins of S. aureus and of C. botulinum, and the enterotoxins of B. cereus are destroyed as well. The emetic toxin of B. cereus is very heat resistant, but has never been shown to be present in raw milk. Because of much shorter processing times UHT and ISI treatment result in a microbial safe product with less quality loss compared to a conventional sterilization process. At higher temperatures microbial inactivation occurs faster than e.g. chemical changes such as the Maillard or browning reaction.

3. Benefits related to raw milk consumption and effect of heating

Several microbiological, nutritional and health benefits of raw cow milk consumption have been assumed, and are by some believed to be destroyed by heating. Additionally, heating is, most probably wrongly, associated with an increased risk of developing various conditions (e.g. milk allergy, lactose intolerance, diabetes, osteoporosis, arthritis). In what follows, these allegations are refuted and/or put into a scientific perspective.

3.1. Nutritional value of milk

From a nutritional point of view milk offers many gains. One of the main arguments of raw milk proponents is that heating reduces the nutritional value of milk, milk being a good source of proteins (essential amino acids), fat (unsaturated fatty acids), vitamins and minerals.

The nutritional value of food not only depends on the nutrient content, but also on the bioavailability and the contribution of these nutrients to the recommended daily intake (RDI). As such, the nutritional value of milk proteins depends on their digestibility and their contribution to the intake of essential amino acids, fat (unsaturated fatty acids), vitamins and minerals.
enzymes and enzyme inhibitors, metal (lactoferrin) and vitamin binding proteins, several growth factors, low molecular weight peptides (proteose-peptone) and bioactive peptides, have important physiological properties (bioactivity) as well. Heating mainly modifies the functional properties of milk proteins (e.g. emulsifying and water binding properties, solubility), but has little effect on their digestibility and nutritional properties (Douglas, Greenberg, & Farrell, 1981; Lacroix et al., 2006).

The most relevant essential amino acid in milk is lysine. Only small losses (1–4%) of the available amount were observed after heating milk (Andersson & Öste, 1995, chap. 13; Schaafsma, 1989; Walstra & Jeness, 1984). The effect of heating on the other amino acids appears to be negligible as well when their levels in raw milk are compared to those in UHT-treated milk (Andersson & Öste, 1995, chap. 13; Souci, Fachmann, & Kraut, 2008).

Concerning milk fat, animal (genetics, stage of lactation, ruminal fermentations,udder infections) and feed (grain, energy and dietary protein intake, seasonal and regional effects) related factors account for variations in the amount and fatty acid composition (Jensen, 2002). The fat content of marketed milk is, however, standardized to a value near that of average raw milk (3.5%), or reduced in case of semi-skimmed milk (1.5–1.8%) or skimmed milk (<0.5% fat) by the removal or addition of cream or the addition of whole milk, semi-skimmed milk or skimmed milk (Council Regulation (EC) 2597/97). Due to the high level of saturated fatty acids (SFA), milk fat is sometimes associated with obesity and cardiovascular diseases (CVD). However, based on a recent review of epidemiological studies there seems to be no consistent relation between a high intake of dairy products and CVD (Astrup et al., 2011). Moreover, some saturated fatty acids in milk are reported to have positive effects on health. For example, butyric acid (4:0) is a known modulator of gene function, and may also play a role in cancer prevention. Caprylic and capric acid (8:0 and 10:0) may have antiviral activities, and caprylic acid has been reported to delay tumor growth. Lauric acid (12:0) may have antiviral and antibacterial functions, and might act as an anti caries and anti plaque agent. Steric acid (18:0) does not seem to increase serum cholesterol concentration, and is not atherogenic (Ebringer et al., 2008; Haug et al., 2007). Additionally, milk contains a rich spectrum of unsaturated fatty acids (e.g. omega-6 and omega-3-fatty acids, conjugated linoleic acid) and important functional components (e.g. sphingolipids), and is an important medium for certain nutrients, such as fat-soluble vitamins (Ebringer et al., 2008; German & Dillard, 2006; Haug et al., 2007).

In humans, the lipid droplet size is a key physico-chemical factor governing fatty acid bioavailability with smaller droplets resulting in higher lipolysis via their surface excess on a larger interface area (Armand et al., 1999; Favé, Coste, & Armand, 2004). It can therefore be postulated that the small droplet size in homogenized milk (mostly performed before or after commercial heating) would thus favor milk fat lipolysis. Furthermore, the ultrastructure of milk fat droplets being an important factor for gastric lipases to gain access to the triacylglycerols (Favé et al., 2004), physico-chemical changes due to homogenization and heating at the interface can positively affect lipase access (Michalski, 2007). Finally, changes observed in the milk fatty acid content (e.g. oxidative damage, isomerization of conjugated linoleic acid) after rather intense processing (200 °C/15 min) appear to be less relevant than feed related or seasonal variations in the milk fatty acid content (Mattila-Sandholm & Saarela, 2003). Commercially heating of milk does not really affect milk lipids.

With respect to vitamins, milk contains all the vitamins in varying concentration, and is not atherogenic (Ebringer et al., 2008; Haug et al., 2007). Heat treatment (mainly pasteurization and UHT) on the availability of the nutritionally relevant vitamins in milk, particularly vitamin B12 (riboflavin) and vitamin B12 (cyanocobalamin), is very low and very few, if any, of vitamins, if any, of natural vitamin content. However, some heat treatments even zero. Only small or no losses have been reported for B6 (pyridoxine), niacin (vitamin B3, niacinic acid, nicotinamide), panthothenic acid (vitamin B5), biotin (vitamin B7) and the fat-soluble vitamins A, D, E and K, even during conventional sterilization of milk (Burton, 1984; Schaafsma, 1989).

Similarly, it can be assumed that there is no difference in the levels of minerals and trace elements between raw and (commercially) heated milk, as is shown in Fig. 2. Milk is in particular a good source of calcium and phosphorus (with the other minerals and trace elements being less relevant). Heat treatment (and homogenization) appears to have no significant effect on the bioavailability of calcium, the major milk mineral (Weeks & King, 1985; Williamson, Finucane, Ellis, & Gamsu, 1978; Zurera-Cosano, Moreno-Rojas, & Amaro-Lopez, 1994).

It should be remarked that, besides the microbiological safety issues, raw milk is nutritionally insufficient for infants and that only milk-based, age-adapted formula fulfills their nutritional

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**Contribution of minerals and trace elements to the recommended daily intake (%RDI) based on the consumption of one large glass of raw or heat-treated milk (250 ml).**

- **Souci et al. (2008), Andersson and Öste (1995, chap. 13), Schaafsma (1989), Belitz and Grosch (1987, chap. 10), and Walstra and Jeness (1984).**
- **No data for Se in UHT milk and for Fe, Cu and Zn in UHT- and sterilized milk.**

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**Fig. 1.** Contribution of vitamins to the recommended daily intake (%RDI) based on the consumption of one large glass of raw or heat-treated milk (250 ml). **Souci et al. (2008), Andersson and Öste (1995, chap. 13), Schaafsma (1989), Belitz and Grosch (1987, chap. 10), and Walstra and Jeness (1984).**

**Fig. 2.** Contribution of minerals and trace elements to the recommended daily intake (%RDI) based on the consumption of one large glass of raw or heat-treated milk (250 ml). **Souci et al. (2008), Schaafsma (2009); no data for Se in UHT milk and for Fe, Cu and Zn in UHT- and sterilized milk.**
requirements. Also with respect to toddlers (up to the age of 3 years), age-adapted milk preparations ("grow up milk") correspond more to their nutritional needs (enough minerals, not too much protein).

3.2. Antimicrobial systems

Raw cow milk contains different systems with antimicrobial properties that inhibit the growth of micro-organisms in raw milk and/or contribute to the immunity of the young calf, amongst which are enzymes (lactoperoxidase, lysozyme, xanthine oxidase) and proteins (lactoferrin, immunoglobulins, bacteriocins) (Table 3). Although the enzymes are inactivated by pasteurization, their activity is limited at refrigeration temperatures used to store raw milk (Griffiths, 2010). Lactoferrin and the immunoglobulins are inactivated above temperatures used for pasteurization. Their activity/concentration is mainly high in colostrum and decreases significantly during lactation to levels of little relevance in the context of raw milk consumption (Korhonen, Marnila, & Gill, 2000; Lewis & Deeth, 2009, chap. 7; Li-Chan, Kummer, Losso, Kitts, & Nakai, 1995; Paulsson, Svensson, Kishore, & Naidu, 1993; Schanbacher et al., 1997; Steijns & van Hooijdonk, 2000; Touch & Deeth, 2009, chap. 3).

Bacteriocins (e.g. nisin) can be produced by micro-organisms present in milk (Lactococcus, Lactobacillus) and most withstand temperatures of 60–100 °C during more than 30 min (Badr, Kareem, Hussein, & El-Hadedy, 2005; Li, Tao, & Hong, 2005; Marinez, Bravo, & Rodriguez, 2005; Ozkalp, Ozden, Tuncer, Sanlibaba, & Akcelik, 2007; Tambekhar & Bhutada, 2010; Touch & Deeth, 2009, chap. 3; Villani et al., 2001). Presently, there is an increasing interest for the antimicrobial and antiviral properties of lipids (e.g. phosphatidylethanolamine, phosphatidylcholine, sphingomyeline) and casein peptide fragments (Dewettinck et al., 2008; German & Dillard, 2006; van Hooijdonk, Kussendrager, & Steijns, 2000; Schanbacher et al., 1997; Zucht, Raida, Adermann, Mägert, & Forssmann, 1995). Their role in raw milk however, needs to be further clarified.

Although almost all antimicrobial systems are inactivated after UHT treatment or sterilization of milk, their activity is no longer required since such milk is by definition commercially sterile.

3.3. Commensal lactic acid bacteria

Commensal lactic acid bacteria present in raw milk inhibit the multiplication of bacteria, including pathogens. Their growth and their lactic acid production are however, limited at the normal refrigeration temperature used to store raw milk. Additionally, above refrigeration temperature the growth of these bacteria provokes rapid degradation of the milk (acidification, coagulation), rendering the milk unsuitable for consumption. Finally, given that some pathogens have a very low infectious dose the inhibiting effect of lactic acid bacteria on pathogen growth can be insufficient in some cases. Pasteurization and sterilization/UHT treatment eliminating the lactic acid bacteria extends the shelf-life of milk. Nevertheless, the elimination of these bacteria in pasteurized milk can have undesirable consequences. Bacterial spores (e.g. B. cereus spores) surviving pasteurization as well as vegetative bacteria that can contaminate milk after pasteurization (post-contamination), grow better in the absence of lactic acid bacteria. Such disadvantage is not relevant for sterilized or UHT milk as this milk is by definition commercially sterile.

3.4. Probiotic bacteria

Probiotic bacteria (specific strains belonging to Lactobacillus, Bifidobacterium and Enterococcus species), are described as health-promoting micro-organisms (Ishibashi & Yamazaki, 2001). Raw milk can contain probiotic bacteria. However, to bring on any beneficial effect, these probiotics need to be ingested in large quantities in order to survive the intestinal transit. In reality, the ingested amount required to have an effect, needs to be 1000 to 10 000 times higher than the amount actually present in raw milk (Griffiths, 2010). Given that these probiotic bacteria represent only certain specific strains potentially present in milk, and given that their growth is inhibited at the refrigeration temperature used to store raw milk, the relevance and the number of these bacteria are too limited to have any physiological effect for consumers. The destruction of these probiotics by pasteurization or sterilization has consequently no net health effects.

3.5. Milk enzymes

Raw milk advocates claim that heating destroys beneficial enzymes, such as alkaline phosphatase and xanthine oxidase. Milk contains numerous enzymes, of which the biological functions or the beneficial effect is mostly unknown. Alkaline phosphatase (EC 3.1.3.1) serves – due to its inactivation at pasteurization conditions – as an indicator for an adequate pasteurization process. In the ‘grey’ literature, alkaline phosphatase is claimed to be critical in the absorption of minerals and calcium (Fassa, 2010). However, no studies were found to affirm this theory. The activity of enzymes is influenced by temperature (most enzymes are inactivated at pasteurization conditions), pH, thermal conductivity, and the availability of substrates, activators and inhibitors. Milk enzymes hardly contribute to the digestibility of milk. Moreover, most milk enzymes are destroyed in the digestive system by pepsin and/or the gastric pH. For example, the activity of xanthine oxid(oreduct)ase (XO/XOR, EC 1.13.22; 1.1.1.204), a component of the milk fat globule membrane that catalyzes the sequential oxidation of hypoxanthine to uric acid via xanthine, is reduced with 36% when milk is incubated with an equal volume of gastric juice, and it is estimated that only 0.00008% of the XO is absorbed in the intestine (Ho & Clifford, 1976). On the other hand, it has been suggested that homogenization of milk prevents the metabolism of XO in the digestive tract, enabling XO to enter the vascular system where it is involved in the development of atherosclerosis (cfr. the plasmonal depletion/xanthine oxidase theory). This hypothesis, however, has been discounted on many scientific grounds (Clifford, Ho, & Swenerton, 1983; European Parliament, 2001, 2002; Michalski & Januel, 2006).

3.6. Milk lactose

Lactose, the main milk carbohydrate, has interesting nutritional properties, such as a low glycemic index and prebiotic properties, and promotes the calcium and magnesium absorption. Free lactose is an important energy source for infants (Schaafsma, 2008). Common pasteurization conditions have no significant effect on the lactose level; raw and pasteurized milk have a similar lactose level. At higher temperatures, lactose reacts in the Maillard reaction with milk proteins or isomerizes into lactulose through the Lobry de Bruyn – Alberda van Ekenstein transformation (Berg, 1993; Berg & van Boekel, 1994; Olano & Martinez-Castro, 1989). Lactulose has been shown to have also prebiotic properties, stimulating the growth of and/or activity of probiotic bacteria including Bifidobacte- ria and Lactobacilli. A range of food products have been developed that contain lactulose as an active ingredient (Ebringer et al., 2008; O’Brien, 1995, chap. 7). Randomized-controlled trials of its effect in a clinical context are few, although animal studies show anti-inflammatory effects in inflammatory bowel disease. Crohn’s disease and ulcerative colitis (Ebringer et al., 2008). Lactulose is additionally known for its laxative effect. Hereto a daily dose of about 2 g lactulose is required (O’Brien, 1995, chap. 7). Based on
<table>
<thead>
<tr>
<th>Milk component</th>
<th>Antimicrobial properties</th>
<th>Remark!</th>
<th>Effect of pasteurization</th>
<th>Effect of UHT treatment</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactoferrin</td>
<td>Iron-binding protein; deprives micro-organisms of Fe, Mg and Ca needed for microbial growth and survival, thereby providing bacteriostatic effects</td>
<td>Lactoferrin level is moderately elevated in colostrum (1–5 mg/ml), but decreases during lactation (0.01–0.1 mg/ml). The bacteriostatic effect (i.e. micro-organisms are not killed, but their growth is inhibited) is abrogated by the citrate concentration in mature milk, and is temporary because some Gram-bacteria can adapt to low iron and synthesize iron chelators. Pepsin digestion of the N-terminus releases bactericidal peptides that are 100–1000 times more potent than intact lactoferrin.</td>
<td>Unheated and pasteurized bovine lactoferrin have similar properties</td>
<td>Denatured; lost of inhibitory capacity</td>
<td>a</td>
</tr>
<tr>
<td>Lactoperoxidase (lactenin) (EC 1.11.1.7)</td>
<td>Contributes to the bacteriostatic properties of milk, in conjunction with other enzymes</td>
<td>The antimicrobial activity requires two chemicals: hydrogen peroxide (produced by some bacteria) and thiocyanate (indigenous). Although both occur normally in milk, addition is required in order to achieve the antibacterial benefits of lactoperoxidase.</td>
<td>Retains 70% of activity when heated to 72 °C for 15 s, the minimum HTST pasteurization process (other studies have shown that Lpo retains almost all its activity at HTST conditions, but loses 90% of activity after 4 min at 75 °C)</td>
<td>Inactivated</td>
<td>b</td>
</tr>
<tr>
<td>Lysozyme (EC 3.1.2.17)</td>
<td>Active primarily against Gram + bacteria; In conjunction with lactoferrin, has bactericidal properties</td>
<td>The amount present in bovine milk is very small (0.4 mg/l)</td>
<td>~75% Activity retained after heating at 80 °C for 15 s</td>
<td>Inactivated</td>
<td>c</td>
</tr>
<tr>
<td>Xanthine oxidase (xanthine oxidoreductase) (EC 1.13.22; 1.1.1.204)</td>
<td>Contributes to the activation of the lactoperoxidase by supplying it with hydrogen peroxide; claimed to have antimicrobial properties</td>
<td>Retains enzymatic activity after heating at 73 °C for 7 min or at 80 °C for 50 s</td>
<td>Inactivated</td>
<td>d</td>
<td></td>
</tr>
<tr>
<td>Bovine immunoglobulin</td>
<td>Transfers immunity against bovine pathogens to calves; may provide some lactogenic immunity in the gut</td>
<td>Most immunoglobulins are carried in the colostrum, which is generally not marketed for human consumption.</td>
<td>No loss of activity during batch pasteurization for 30 min at 62.7 °C; retains 59–76% of activity after HTST pasteurization</td>
<td>Denaturated</td>
<td>e</td>
</tr>
<tr>
<td>Nisin &amp; Bacteriocins</td>
<td>Antimicrobial peptides that are produced by lactic acid bacteria that may be present in milk (Lactococcus, Lactobacillus, Enterococcus); antimicrobial activity against Gram + bacteria Nisin belongs to a class of bacteriocins known as lantibiotics</td>
<td>Many lactic acid bacteria are capable of producing bacteriocins, but it is unlikely that they would reach levels necessary for the production of bacteriocins in refrigerated milk as they would not grow Raw milk contains negligible levels of nisin</td>
<td>Heat stable and retain activity after pasteurization</td>
<td>Different heat stabilities. Many can withstand temperatures range between 60 and 100 °C for more than 30 min, and some have been shown to resist heating up to 121 °C/10 min in culture supernatant High temperature tolerance (120 °C/10 min in solution)</td>
<td>f</td>
</tr>
<tr>
<td>Oligosaccharides</td>
<td>Competitively bind to pathogens to prevent adhesion of pathogens to the intestinal epithelium</td>
<td>Levels of oligosaccharides in bovine milk are very low compared with human milk. The highest concentration is found in colostrums and drops postparturition to trace levels.</td>
<td>Heat stable</td>
<td>Most likely no effect</td>
<td>g</td>
</tr>
</tbody>
</table>

(continued on next page)
lactulose values measured in heated milk, this amount is not easily acquired by drinking milk alone, and corresponds to 12.5 l of pasteurized milk, 2.6 l of UHT milk and 0.8 l of sterilized milk.

Apart from storage conditions, the lactose content of raw milk can be considered to be zero. Lactose and its derivative lactulose (which is formed by heating) have both nutritional and health beneficial properties.

### 3.7. Milk allergy and lactose intolerance

Milk allergy is a reaction linked to the immune system. Several studies concerning the relative antigenicities of milk proteins suggest that the main allergenic component is β-lactoglobulin, with α-lactalbumin, bovine serum albumin (BSA), lactoferrin and caseins being less antigenic. The most effective method to reduce the antigenicity of milk is to remove the allergenic compounds or to reduce the molecular mass of the principal milk allergen (e.g. by hydrolysis). Milk processing (heating, homogenization) can increase (formation or unmasking of epitope structures) or decrease milk allergy (destruction or shielding of epitopes), depending on the protein (or component) involved and on the individual patient (Ehn, Ekstrand, Bengtsson, & Ahlstedt, 2004; Michalski, 2007; Swenning, Brynhildsvold, Molland, Langsrud, & Vegarud, 2000). On the other hand, it has been suggested that pasteurization could contribute to the initial sensitization step (but only soluble proteins would trigger anaphylaxis) (Roth-Walter et al., 2008), and that early Maillard reaction products may exacerbate milk allergic reactions in susceptible subjects (Kilshaw, Heppell, & Ford, 1982). Overall, however, milk allergy is independent of the fact that milk has been heated (homogenized) or not.

Lactose intolerance is the inability to digest lactose by a deficiency of the enzyme lactase (β-galactosidase). Fermented milk products (e.g. yoghurt, fermented cheese) are fairly well tolerated by lactose intolerant people because lactose is hydrolyzed (“pre-digested”) by the microbial lactase present in these products (Schaafsma, 2008). In the same sense, raw milk proponents claim that heating milk destroys the lactase or the lactic acid bacteria that can hydrolyze lactose. All milk, raw or heated (and/or homogenized) contains lactose and no lactase (FDA, 2005; Panesar, Kumari, & Panesar, 2010). The lactase production by lactic acid bacteria in raw milk is limited as milk is kept at refrigeration temperature.

### 3.8. Allergies and immunity, diabetes, osteoporosis and arthritis

A number of epidemiological studies suggest that early-life exposure to unprocessed cow milk could reduce the risk for developing asthma, allergic rhinitis, hay fever, pollen allergy and atopic sensitization (Barnes et al., 2001; Loss et al., 2011; Perkin & Strachan, 2006; Riedler et al., 2001; Waser et al., 2007; Wickens et al., 2002). Proposed hypotheses for this positive effect of raw milk consumption include the intake of non-infectious microbial components (e.g. endotoxins), the natural amount of milk fat and unsaturated fatty acids (unprocessed farm milk being generally richer in fat than commercial milk, of which the fat content is standardized), differences in milk proteins (e.g. bioactive peptides) and allergy causing structures, and the presence of immunoglobulins (Braun-Fahrländer & von Mutius, 2011; Gehring et al., 2008; Grifths, 2010).

In analogy, it is hypothesized that frequent consumption of raw milk could create a higher immunity against symptomatic infections caused by pathogens, as a result of the development of a cross-immunity due to a repeated exposition to non-virulent strains/variants of these pathogens. The only example found in literature though is specific for Campylobacter (Blaser, Duncan, Osterholm, Istre, & Wang, 1983; Blaser, Sazie, & Williams, 1987).
Most studies alluding to a possible protective effect of raw milk consumption, do not contain any objective confirmation on the raw milk status (home-cooked or not) or a direct comparison with heat-treated milk. Moreover, it seems that the observed increased resistance seems to be rather related to the exposure to a farm environment or to animals than to raw milk consumption (Kilpeläinen, Terho, Helenius, & Koskenvuo, 2000).

There are only a very limited number of studies regarding the influence of (raw, heated or homogenized) milk consumption on the development of diabetes. Moreover, the available data are controversial (Astrup et al., 2011; Gille, 2009; Michalski, 2007; Michalski & Januel, 2006; Wasmuth & Kolb, 2000). A role of A1–β-casein (a variant of β-casein), and in particular of β-casomorphin 7 formed from A1–β-casein during storage or processing, has been suggested in the development of type 1 diabetes, autism and CVD. However, based on a review of available scientific literature, the European Food Safety Agency (EFSA) concluded that a cause-effect relationship between the oral intake of β-casomorphin 7 or related peptides and etiology or course of any suggested non-communicable diseases cannot be established (EFSA, 2009b).

Similarly, there are no scientific indications for a possible link between the consumption of heat-treated milk and osteoporosis or arthritis (FDA, 2005). The uptake of calcium, important for bone formation, is amongst others influenced by the presence of vitamin D, the concentration of soluble calcium salts and phosphopeptides of milk casein (Guéguen & Pointillart, 2000). As already mentioned, heat treatment of milk does not affect the content nor the bioavailability of calcium in a significant way.

### 3.9. Organoleptic profile

The only substantial counter-argument against heating milk is that heating changes the organoleptic profile of raw milk. Various mechanisms and sources at different stages of the production chain (from farm to fork) may affect the organoleptic profile of milk. They can be of a chemical nature (e.g. "cooked" flavor associated with the presence of a variety of sulfur containing compounds, "stale" flavor characterized by the dissipation of sulfur volatiles and formation of methyl ketones and aliphatic aldehydes), of enzymatic nature (e.g. rancidity by endogenous or microbial lipase activity), or of microbial nature (e.g. acid flavor due to Streptococcus and Lactobacillus) (Adhikari & Singhal, 1991; Bassette, Fung, & Mantha, 1986; Clark, Costello, Drake, & Bodyfelt, 2008; Contarini, Povolo, Leardi, & Toppino, 1997; McSweeney & Fox, 2009; Zabbia, Buys, & De Kock, 2012). Some of these flavor ‘defects’ can be annulled or reduced by heating (e.g. microbial reduction, enzyme inactivation, etc.), while others are induced by heating. Low-pasteurized milk is almost free of heating flavors, while high-pasteurized milk can

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Overview of the risks &amp; benefits related to the consumption of raw/heat-treated milk.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw milk</td>
</tr>
<tr>
<td><strong>(Purported) risks</strong></td>
<td></td>
</tr>
<tr>
<td>Pathogens</td>
<td>Elevated risk, especially for Campylobacter jejuni &amp; coli, Salmonella, human pathogenic verocytotoxigenic E. coli</td>
</tr>
<tr>
<td>Nutritive value</td>
<td>Important source of calcium, phosphor, essential amino acids (especially lysine), and the vitamins B2 and B12.</td>
</tr>
<tr>
<td>Antimicrobial systems</td>
<td>Limited activity of most antimicrobial enzymes at the refrigeration temperature used to store raw milk</td>
</tr>
<tr>
<td>Lactic acid bacteria</td>
<td>Limited growth at refrigeration temperature used to store raw milk</td>
</tr>
<tr>
<td>Probiotic bacteria</td>
<td>Growth is too limited to have beneficial effects</td>
</tr>
<tr>
<td>&quot;Beneficial&quot; milk enzymes</td>
<td>“Beneficial” effect has not been found in literature</td>
</tr>
<tr>
<td>Lactose destruction</td>
<td>Lactose content of raw and pasteurized milk are similar</td>
</tr>
<tr>
<td>Milk allergy &amp; lactose intolerance</td>
<td>Presence of allergenic components as well as of lactose (amount of lactic acid bacteria and their lactase production is very limited at storage temperature)</td>
</tr>
<tr>
<td>Increased immunity</td>
<td>(on the contrary, raw milk-borne diseases have been reported)</td>
</tr>
<tr>
<td>Diabetes, osteoporosis, arthritis</td>
<td>Data in support are very limited to inexistent and controversial</td>
</tr>
<tr>
<td>Organoleptic profile</td>
<td>Perception factor: marketed whole milk is standardized and has generally a lower fat content than farm milk</td>
</tr>
</tbody>
</table>
have a cooked flavor mainly caused by the formation of H₂S. This cooked flavor is especially present immediately after processing, and its intensity diminishes during storage (Clark et al., 2008). Although homogenization renders milk more susceptible to hydrolytic racidity due to increased lipoprotein lipase activity, this enzyme is inactivated by heating (pasteurization), which is in practice usually performed either immediately before or after the homogenization process (Deeth, 2006; Fox & McSweeney, 2006).

Nevertheless, the organoleptic or sensorial perception is mainly determined by the milk fat content (cf. skimmed versus whole milk). The fat content of commercial (whole) milk is standardized and generally lower than the fat content of fresh cow milk (3.5% compared to ~4%: Council Regulation (EC) 2557/97). Additionally, relatively new processing techniques (e.g. ESL or extended shelf-life milk) and packaging materials have been developed to minimize the undesirable off-flavors or to produce safe milk with a similar taste of fresh milk. Moreover, a wide range of milk products with different flavors or with different added compounds is available on the market to diversify the tastes and flavors in order to meet consumers’ demand.

4. Conclusions

In this evaluation it is clearly demonstrated that the consumption of raw milk poses a realistic and unnecessary health threat because of its possible contamination with pathogenic bacteria. It is therefore recommended to heat milk before consumption, especially when served to young children, pregnant women, or any person suffering from a chronic disease or a suppressed immune system. In this context the attention is drawn to raw milk provided on farms to the general public (e.g. during a school visit) and raw milk from a bulk reservoir to the consumer. From a nutritional point of view, milk is a highly nutritious food and whole milk could be avoided by a heat treatment. At present, thermal treatment remains the most frequently used and most effective method to increase the microbiological safety of milk without substantially changing the nutritional value of milk or other benefits associated with raw milk consumption. Table 4 summarizes the main (claimed) benefits of raw milk consumption and the (claimed) detrimental effects of heating discussed in the present paper. Almost all arguments put forward by raw milk proponents for not using heat treatment can be refuted, and the only substantial disadvantage of pasteurization is the change in the organoleptic properties of milk. It is clear that this ‘detrimental’ effect of heating does not countervail the risk posed by raw milk consumption, namely of a milk-borne pathogen infection, which can have serious health consequences.

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