Food Control 31 (2013) 251–262

Contents lists available at SciVerse ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Review

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

Wendie L. Claeys[a,*], Sabine Cardoen[a], Georges Daube[b], Jan De Block[c], Koen Dewettinck[d,e], Katelijne Dierick[d,f], Lieven De Zutter[d,e], André Huyghebaert[d,e], Hein Imberechts[d,f], Pierre Thiange[g], Yvan Vandenplas[h], Lieve Herman[c,d]

[a] DG Policy Control, Federal Agency for the Safety of the Food Chain (FASFC), 1000 Brussels, Belgium
[b] University of Liège, 4000 Liège, Belgium
[c] Flemish Institute for Agricultural and Fisheries Research (ILVO), 9090 Melle, Belgium
[d] Scientific Committee, Federal Agency for the Safety of the Food Chain (FASFC), 1000 Brussels, Belgium
[e] University of Ghent, 9000 Ghent, Belgium
[f] Scientific Institute of Public Health, 1000 Brussels, Belgium
[g] Association Régionale de Santé et de l'Identification Animales (ARSIA), 5590 Ciney, Belgium
[h] UZ Brussel, Vrije Universiteit Brussel, 1090 Brussels, Belgium

ARTICLE INFO

Article history:
Received 29 March 2012
Received in revised form
14 September 2012
Accepted 25 September 2012

Keywords:
Raw milk
Pathogens
Risk/benefit
Nutrition
Heat treatment

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 *Campylobacter*, *Salmonella* spp. and human pathogenic verocytotoxin-producing *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 micro-organisms, 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% (FDA, 2011). Between 1880 and 1907, 29 milk-borne outbreaks

* Corresponding author. Staff Direction for Risk Assessment, FAVV-AFSCA, Boulevard du Jardin Botanique 55, B-1000 Brussels, Belgium. Tel.: +32 (0)2 211 87 02; fax: +32 (0)2 211 87 22.
E-mail address: wendie.claeys@favv.be (W.L. Claeys).

0956-7135/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.foodcont.2012.09.035

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 of the incidence of diseases related to liquid milk consumption (Barrett, 1986; Burt & Wellsteed, 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-sporogenic 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* (Spreer, 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 1–5% of the total bacterial foodborne outbreaks, with 39.1% attributed to milk, 53.1% to cheese and 7.8% to other milk products (De Buyser et al., 2001).

Whereas milk quality and safety has been the topic of many research studies, raw milk still continues to be an issue for debate, which is primarily held on the internet where often non-scientifically based information circulates (Fassa, 2010; Organic Pastures, 2008; Raw-milk-facts.com, 2008). Therefore, the aim of this study is to evaluate the risks and benefits related to the consumption of raw cow milk at one hand, and to evaluate the effect of heat treatments of milk on these risks and benefits on the other hand, considering the microbiological as well as the nutritional (health) aspects.

2. Risks related to raw milk consumption and effect of heating

The risks associated with raw milk consumption are mainly of a microbiological nature, and raw cow milk does not really pose any risks at nutritional level. (The presence of residues and contaminants such as antibiotics, mycotoxins M1 and M2, etc., are out of the scope of this study.)

2.1. Pathogens potentially present in raw cow milk

There are multiple and diverse sources of microbial contamination of raw cow milk. Human pathogens potentially encountered in raw cow milk as well as their possible sources of contamination, are presented in Table 1.

From the pathogens listed in Table 1, *Salmonella* spp., *Campylobacter* spp., *E. coli* O157:H7, *Y. enterocolitica* and *L. monocytogenes* as well as intoxications by *S. aureus* are most frequently identified as the cause of human outbreaks due to the consumption of raw milk or products made thereof (Barrett, 1986; De Buyser et al., 2001; Galbraith et al., 1982; Gillespie et al., 2003; Lee & Middleton, 2003; Oliver, Boor, Murphy, & Murinda, 2009). Considering only raw milk consumption as the source of a human outbreak, essentially three micro-organisms are frequently reported, namely in order of decreasing reporting frequency *Campylobacter* spp., *Salmonella* spp. and human pathogenic verocytotoxigenic *E. coli* (*E. coli* O157:H7 and pathogenic *E. coli* non-O157:H7) (Griffiths, 2010; Oliver, Jayarao, & Almeida, 2005; Vogt, Donnelly, Gellin, Bibb, & Swaminathan, 1990) (Table 2).

The significance of *L. monocytogenes* and *S. aureus* in terms of outbreaks due to raw cow milk consumption is very low. For *L. monocytogenes* only two human cases were reported in relation to the consumption of raw cow milk and both outside Europe (Table 2); no human cases/outbreaks were reported in relation to enterotoxins 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 risks 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 micro-organism (or the toxicity of the toxin), the number of ingested micro-organisms (or quantity of toxins), the human infective dose, and the health status of the consumer (D'Aoust, 1989; Lund & O'Brien, 2011). People most at risk are the very young, elderly persons, pregnant women and immune-compromised persons (YOPIs), although anyone can be affected, including healthy young adults

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

	Direct passage from the blood into the milk (systemic infection)	Mastitis (udder infection)	Faecal contamination (external contamination of the milk during or after milking)/contamination from skin	Environmental sources
Pathogenic bacteria				
Salmonella spp.	*(x) (S. Dublin)*	*(x)*	*x*	*x*
Brucella abortus	*x*	*(x)*		*x*
Mycobacterium bovis	*x*		*x*	*x*
Coxiella burnetii	*x*		*x*	*x*
Mycobacterium avium subsp. *paratuberculosis*[a]	*x*		*x*	*x*
Listeria monocytogenes	*x*	*x*	*x*	*x*
Human pathogenic verocytotoxigenic *E. coli*[b]			*x*	*x*
Campylobacter coli and *jejuni*			*x*	*x*
Corynebacterium pseudotuberculosis	*(x)*	*(x)*		
Human pathogenic *Yersinia*[c]		*x*[d]	*x*	*x*
Bacillus cereus[e]				*x*
Enterotoxin producing *Staphylococcus aureus*		*x*		*x*
Arcanobacter pyogenes		*x*		
Streptococcus zooepidemicus		*x*		
Leptospira	*x*			*x (Urine)*
Pathogenic viruses				
Rift valley fever virus	x			
Viruses of the tick-borne encephalitis (TBE) complex (of which the Central European encephalitis virus)	x			
Pathogenic parasites				
Cryptosporidium parvum			x	x
Microbial toxins				
Type B toxins of *Clostridium botulinum*	*x (Toxins)*		*x (Spores)*	*x (Spores)*

(x) Rarely.
[a] Potentially zoonotic.
[b] 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).
[c] *Y. enterocolitica* and *Y. pseudotuberculosis* (Shwimmer et al., 2007). Only *Y. enterocolitica* biotypes 1b, 2, 3, 4 and 5 of are pathogenic to humans.
[d] Only *Y. pseudotuberculosis*.
[e] 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.

(Griffiths, 2010). The consequences of a milk-borne infection may be limited to the common symptoms of diarrhea, vomiting, nausea, fever, abdominal cramps, etc., but a certain percentage of persons can develop more severe clinical symptoms such as Guillain-Barré syndrome (*Campylobacter* spp.) and hemolytic uremic syndrome (HUS) (*E. coli* O157:H7), or long-term and sometimes chronic complications, e.g. reactive arthritis, or even death. Assuming a score of severity on a scale from 1 to 4 (with 4 for the most serious effect) for the pathogens frequently encountered in raw milk related outbreaks, a score of 3, 3, 4 and 4 can be assigned to *Campylobacter* spp., *Salmonella* spp., human pathogenic *E. coli* and *L. monocytogenes* respectively.

The presence of pathogens in raw cow milk is estimated for *Campylobacter*, *Salmonella*, human pathogenic verocytotoxigenic *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 presence 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 2
Evaluation of the relative microbial risk associated with raw milk consumption.

Pathogen	Presence in dairy cattle farms in Belgium[a]	Presence in raw cow milk in Europe[b]	Indication of number of outbreaks after raw cow milk consumption in Europe and worldwide[c]
Salmonella spp.	Present	0–2.9%	5 (Europe) or 39 (world)
Campylobacter jejuni and coli	Present	0–6%	18 (Europe) or 39 (world)
Human pathogenic *E. coli*	Present	0–5.7%	13 (Europe) or 28 (world)
Listeria monocytogenes[e]	Present	2.2–10.2%[d]	0 (Europe) or 2 (world)

[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, 1999; McKee, Madden, & Gilmour, 2003; Mechie, Chapman, & Siddons, 1997; Messelhäusser, Beck, Gallien, Schalchl, & 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, O103, O111 en O145, rendering the estimation of the prevalence of these serotypes difficult (Vernozy-Rozand & Roze, 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, 1995; Fenlon & Wilson, 1989; Greenwood, Roberts, & Burden, 1991; Hahn et al., 1999; Harvey & Gilmour, 1992; Jouve & Lahellec, 1991; Meyer-Broseta, Diot, Bastian, Rivière, & 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 10^6), 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 wrongfully, 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. Approximately 80% of the milk proteins consist of casein (αs1, αs2-, β- and κ-casein). Casein molecules are precursors of several bioactive peptides, with antimicrobial activity and vector properties for calcium, zinc, copper, iron and phosphate ions in the body (Ebringer, Ferenčik, & Krajčovič, 2008). Bioactive peptides are short amino acid chains that are inactive in the native protein, but have a physiological effect in the body after liberation by e.g. digestive enzymes or processing (Haug, Høstmark, & Harstad, 2007; Korhonen, Pihlanto-Leppälä, Rantamäki, & Tupasela, 1998; Schanbacher, Talhouk, & Murray, 1997). The other milk proteins, whey or serum proteins, including α-lactalbumin, β-lactoglobulin, serum albumin, immunoglobulins, 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. Stearic 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 amounts, but not all vitamins present are of nutritional importance in a Western diet. This is illustrated in Fig. 1, where the vitamin content of raw and heated milk is presented in terms of percentage of the recommended daily intake (RDI) based on the consumption of 1 large glass of milk (~250 ml). To achieve the RDI of, for example, the heat sensitive vitamin B_1 (thiamine) and of vitamin C (ascorbic acid), at least 20 l of raw milk should be consumed. The effect of a heat treatment (mainly pasteurization and UHT) on the availability of the nutritionally relevant vitamins in milk, particularly vitamin B_2 (riboflavin) and vitamin B_{12} (cyanocobalamin), is very low and for some heat treatments even zero. Only small or no losses have been reported for B_6 (pyridoxine), niacin (vitamin B_3, nicotinic acid, nicotinamide), panthothenic acid (vitamin B_5), biotin (vitamin B_7) and the fat-soluble vitamins A, D and E, even during conventional sterilization of milk (Burton, 1984; Schaafsma, 1989).

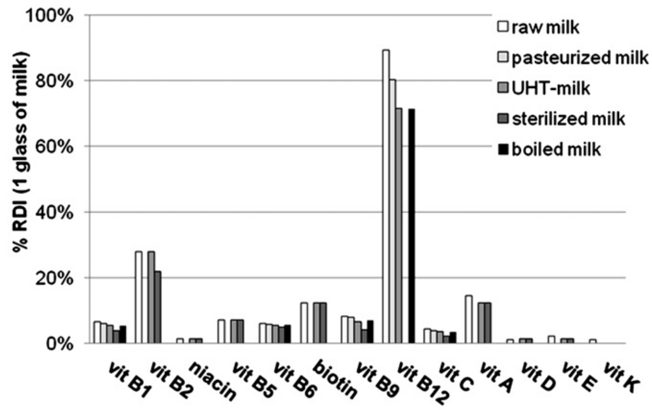

Fig. 1. Contribution of vitamins[a] to the recommended daily intake (%RDI)[b] based on the consumption of one large glass of raw or heat-treated milk (250 ml). [a]Souci et al. (2008), Andersson and Öste (1995, chap. 13), Schaafsma (1989), Belitz and Grosch (1987, chap. 10), and Walstra and Jeness (1984). [b]BSHC (2009). No data for vitamins B_2, B_5, A, D, E, K, niacin and biotin in pasteurized and boiled milk, and for vitamin K in UHT- and sterilized milk.

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

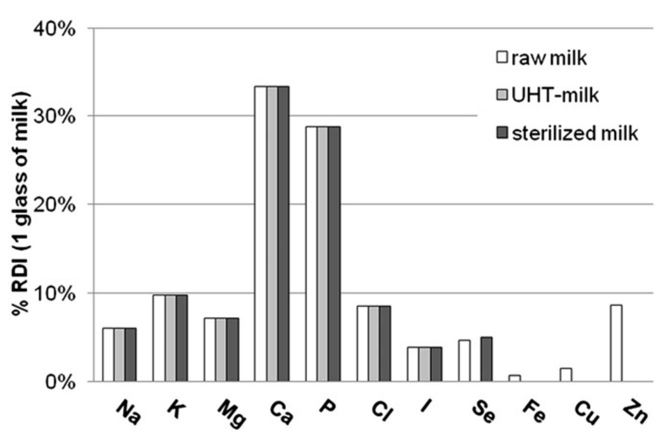

Fig. 2. Contribution of minerals and trace elements[a] to the recommended daily intake (%RDI)[b] based on the consumption of one large glass of raw or heat-treated milk (250 ml).[a] Souci et al. (2008); [b]BSHC (2009); no data for Se in UHT milk and for Fe, Cu and Zn in UHT- and sterilized milk.

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, Karem, Hussein, & El-Hadedy, 2005; Li, Tao, & Hong, 2005; Marinez, Bravo, & Rodriguez, 2005; Özkalp, Özden, Tuncer, Sanlibaba, & Akçelik, 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, sphyngomyeline) 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 metabolization of XO in the digestive tract, enabling XO to enter the vascular system where it is involved in the development of atherosclerosis (cfr. the plasmalogen 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 *Bifidobacteria* 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 3
Main antimicrobial systems in milk.

Milk component	Antimicrobial properties	Remark!	Effect of pasteurization	Effect of UHT treatment	Ref.
Lactoferrin	Iron-binding protein; deprives micro-organisms of Fe, Mg and Ca needed for microbial growth and survival, thereby providing bacteriostatic effects	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.	Unheated and pasteurized bovine lactoferrin have similar properties	Denatured; lost of inhibitory capacity	[a]
Lactoperoxidase (lactenin) (EC 1.11.1.7)	Contributes to the bacteriostatic properties of milk, in conjunction with other enzymes	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.	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)	Inactivated	[b]
Lysozyme (EC 3.1.2.17)	Active primarily against Gram+ bacteria; In conjunction with lactoferrin, has bactericidal effects	The amount present in bovine milk is very small (0.4 mg/l)	>75% Activity retained after heating at 80 °C for 15 s	Inactivated	[c]
Xanthine oxidase (xanthine oxidoreductase) (EC 1.13.22; 1.1.1.204)	Contributes to the activation of the lactoperoxidase by supplying it with hydrogen peroxide; claimed to have antimicrobial properties		Retains enzymatic activity after heating at 73 °C for 7 min or at 80 °C for 50 s	Inactivated	[d]
Bovine immunoglobulin	Transfers immunity against bovine pathogens to calves; may provide some lactogenic immunity in the gut	Most immunoglobulins are carried in the colostrum, which is generally not marketed for human consumption.	No loss of activity during batch pasteurization for 30 min at 62.7 °C; retains 59–76% of activity after HTST pasteurization	Denaturated	[e]
Nisin & Bacteriocins	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	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	Heat stable and retain activity after pasteurization	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)	[f]
Oligosaccharides	Competitively bind to pathogens to prevent adhesion of pathogens to the intestinal epithelium	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.	Heat stable	Most likely no effect	[g]

(*continued on next page*)

Table 3 (*continued*)

Milk component	Antimicrobial properties	Remark!	Effect of pasteurization	Effect of UHT treatment	Ref.
Lipid fragments*, phosphatidylethanolamine, phosphatidylcholine, sphyngomyeline	Particularly against Gram+ bacteria *(fatty acids with chain lengths varying from 8 to 12 carbons appear to be more antiviral and antibacterial than long-chain monoglycerides)	Hydrolysis may be significant for individual fatty acids to exert an antimicrobial effect	Most likely no effect	Most likely no effect	h
Protein fragments (peptides from α- and β-caseins)		While some bioactivities are fully active in native proteins, others are latent until proteolytic release	Most likely no effect	Most likely no effect	i

* Fatty acids with chain lengths varying from 8 to 12 carbons appear to be more antiviral and antibacterial than long-chain monoglycerides.
[a] Touch and Deeth (2009), Steijns and van Hooijdonk (2000), Schanbacher et al. (1997), and Paulsson, Svensson, Kishore, and Naidu (1993).
[b] Claeys, Van Loey, and Hendrickx (2002), Marks, Grandison, and Lewis (2001), and Griffiths (1986).
[c] Fox and Kelly (2006).
[d] Fox and Kelly (2006), Stevens et al. (2000), Farkye and Imafidon (1995, chap. 16), and Demott and Praepanitchai (1978).
[e] Lewis and Deeth (2009), Korhonen et al. (2000), and Li-Chan et al. (1995).
[f] Tambekhar and Bhutada (2010), Touch and Deeth (2009), Özkalp et al. (2007), Badr et al. (2005), FDA (2005), Li et al. (2005), Marinez et al. (2005), and Villani et al. (2001).
[g] Martín, Martín-Sosa, and Hueso (2002) and Gopal and Gill (2000).
[h] Dewettinck et al. (2008), German and Dillard (2006), and van Hooijdonk et al. (2000).
[i] Schanbacher et al. (1997) and Zucht et al. (1995).

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 lactulose 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; Svenning, 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; Griffiths, 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 I 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 4
Overview of the risks & benefits related to the consumption of raw/heat-treated milk.

	Raw milk		Heating	
	(Purported) risks			
Pathogens	Elevated risk, especially for *Campylobacter jejuni & coli*, *Salmonella*, human pathogenic verocytotoxigenic *E. coli*	−−	Pasteurization: Inactivation of vegetative pathogens, survival of bacterial spores, no reduced activity of bacterial toxins UHT: commercially sterile product, destruction of relevant bacterial toxin activity	++
	(Purported) benefits (or detrimental effects caused by heating)			
Nutritive value	Important source of calcium, phosphor, essential amino acids (especially lysine), and the vitamins B_2 and B_{12}.	+	effect on the deliverance of these nutrients is negligible	+
Antimicrobial systems	Limited activity of most antimicrobial enzymes at the refrigeration temperature used to store raw milk	+	Pasteurization: many (except enzymatic) antimicrobial systems retain almost all their antimicrobial activity UHT: most endogenous antimicrobial activities are obliterated, but their activity is no longer needed since the milk is commercially sterile	+
Lactic acid bacteria	Limited growth at refrigeration temperature used to store raw milk	+	Inactivation by pasteurization and other treatments; Pasteurization may lead to bacterial spore germination − outgrowth spores and post-contaminating bacteria possible	−/+
Probiotic bacteria	Growth is too limited to have beneficial effects	n/a	Destruction by heat has no net health effect	n/a
"Beneficial" milk enzymes	"Beneficial" effect has not been found in literature	n/a	Enzyme inactivation by heat seems to have no nutritional nor health effects (moreover, most enzymes are inactivated in the gastro-intestinal tract)	n/a
Lactose destruction	Lactose content of raw and pasteurized milk are similar	+	Lactose decrease at higher (UHT) temperatures with formation of lactulose, which also has a nutritional value	+
Milk allergy & lactose intolerance	Presence of allergenic components as well as of lactose (amount of lactic acid bacteria and their lactase production is very limited at storage temperature)	n/a	Presence of allergenic components as well as of lactose	n/a
Increased immunity	Scientific evidence to support this claim is arguable (on the contrary, raw milk-borne diseases have been reported)	n/a	No relevance	n/a
Diabetes, osteoporosis, arthritis	Data in support are very limited to inexistent and controversial	n/a	No relevance	n/a
Organoleptic profile	Perception factor: marketed whole milk is standardized and has generally a lower fat content than farm milk	+	Flavor changes due to heat are possible (although small in case of UHT or ISI)	−

have a cooked flavor mainly caused by the formation of H_2S. 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 rancidity 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 (cfr. 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) 2597/97). Additionally, relatively new processing techniques (e.g. ESL or extended shelf-life and ISI, but also UHT) 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 distributors allowing the automatic supply of raw milk from a bulk reservoir to the consumer. From a nutritional point of view, infants should only be given "infant formula" since unprocessed milk does not fulfill the nutritional needs of this age group.

Historical data show that the pasteurization of milk has led to an improved public health and more recent data on occasional raw milk consumption indicate the hazard of bacterial infections, which 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 heating milk, can be refuted, and the only substantial disadvantage of heating is the change in the organoleptic profile 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.

Acknowledgment

The authors wish to thank the Scientific Committee of the Belgian Federal Agency for the Safety of the Food Chain (FASFC), M. Uyttendaele (Scientific Committee FASFC, University of Ghent), E. Daeseleire (Scientific Committee FASFC, ILVO), W. Stevens (UA), and I. Coene (NICE) for their scientific support.

References

Adhikari, A., & Singhal, O. (1991). Changes in the flavour profile of indirectly heated UHT milk during storage: effect of Maillard browning and some factors affecting it. *Indian Journal of Dairy Science, 44*, 442–448.

Andersson, I., & Öste, R. (1995). Nutritional quality of heat processed liquid milk. In P. F. Fox (Ed.), *Heat-induced changes in milk* (2nd ed.) (pp. 279–307). Brussels: International Dairy Federation.

Armand, M., Pasquier, B., André, M., Borel, P., Senft, M., Peyrot, J., et al. (1999). Digestion and absorption of 2 fat emulsions with different droplet sizes in the human digestive tract. *American Journal of Clinical Nutrition, 70*, 1096–1106.

Astrup, A., Dyerberg, J., Elwood, P., Hermansen, K., Hu, F. B., Jakobsen, M. U., et al. (2011). Perspective: the role of reducing intakes of saturated fat in the prevention of cardiovascular disease: where does the evidence stand in 2010? *American Journal of Clinical Nutrition, 93*, 684–688.

Bachmann, H. P., & Spahr, U. (1995). The fate of potentially pathogenic bacteria in Swiss hard and semihard cheeses made from raw milk. *Journal of Dairy Science, 78*, 476–483.

Badr, S., Karem, A., Hussein, H., & El-Hadedy, D. (2005). Characterization of nisin produced by *Lactococcus lactis*. *International Journal of Agriculture and Biology, 7*, 499–503.

Barnes, M., Cullinan, P., Athanasaki, P., MacNeill, S., Hole, A. M., Harris, J., et al. (2001). Crete: does farming explain urban and rural differences in atopy? *Clinical & Experimental Allergy, 31*, 1822–1828.

Barrett, N. J. (1986). Communicable disease associated with milk and dairy products in England and Wales: 1983–1984. *Journal of Infection, 12*, 265–272.

Bassette, R., Fung, D., & Mantha, V. (1986). Off-flavors in milk. *CRC Critical Reviews in Food Science and Nutrition, 24*, 1–52.

Belitz, H. D., & Grosch, W. (1987). *Food chemistry*. Berlin: Springer-Verlag.

Berg, H. (1993). *Reactions of lactose during heat treatment of milk: A quantitative study*. Ph.D. thesis, Wageningen Agricultural University, The Netherlands.

Berg, H., & van Boekel, M. (1994). Degradation of lactose during heating of milk. I. Reaction pathways. *Netherlands Milk and Dairy Journal, 48*, 157–175.

Beumer, R. R., Cruysen, J. J., & Birtantie, I. R. (1988). The occurrence of *Campylobacter jejuni* in raw cows' milk. *Journal of Applied Bacteriology, 65*, 93–96.

Blaser, M. J., Duncan, D. J., Osterholm, M. T., Istre, G. R., & Wang, W. L. (1983). Serologic study of two clusters of infection due to *Campylobacter jejuni*. *Journal of Infectious Diseases, 147*, 820–823.

Blaser, M. J., Sazie, E., & Williams, L. P., Jr. (1987). The influence of immunity on raw milk-associated *Campylobacter* infection. *Journal of the American Medical Association, 257*, 43–46.

Braun-Fahrländer, C., & von Mutius, E. (2011). Can farm milk consumption prevent allergic diseases? *Clinical & Experimental Allergy, 41*, 29–35.

BSHC – Belgian Superior Health Council. (2009). *Recommandations nutritionnelles pour la Belgique (Révision 2009) HGR/CSS 8309* (p. 114). Brussels: BSHC. <http://www.health.belgium.be/internet2Prd/groups/public/@public/@shc/documents/ie2divers/18014679_fr.pdf>.

Burt, R., & Wellsteed, S. (1991). Food safety and legislation in the dairy industry. *International Journal of Dairy Technology, 44*, 80–86.

Burton, H. (1984). Reviews of the progress of dairy science: the bacteriological, chemical, biochemical and physical changes that occur in milk at temperatures of 100–150 °C. *Journal of Dairy Research, 51*, 341–363.

CDC – Centers for Disease Control and Prevention. (2008). *Escherichia coli* O157:H7 infections in children associated with raw milk and raw colostrums from cows – California, 2006. *Morbidity and Mortality Weekly Report, 57*, 625–628.

Claeys, W., Van Loey, A., & Hendrickx, M. (2002). Intrinsic time temperature integrators for heat treatment of milk. *Trends in Food Science & Technology, 13*, 293–311.

Clark, S., Costello, M., Drake, M., & Bodyfelt, F. W. (2008). *The sensory evaluation of dairy products* (2nd ed.) (p. 576). New York: Springer Science + Business Media, Inc.

Clifford, A. J., Ho, C. Y., & Swenerton, H. (1983). Homogenized bovine milk xanthine oxidase: a critique of the hypothesis relating to plasmalogen depletion and cardiovascular disease. *American Journal of Clinical Nutrition, 38*, 327–332.

Coia, J. E., Johnston, Y., Steers, N. J., & Hanson, M. F. (2001). A survey of the prevalence of *Escherichia coli* O157 in raw meats, raw cow's milk and raw-milk cheeses in south-east Scotland. *International Journal of Food Microbiology, 66*, 63–69.

Colombo, S., Pacciarini, M. L., & Fusi, P. (1998). Isolation of a new phenotypic variant of *E. coli* O157:H7 from food. *The Veterinary Record, 142*, 144–145.

Contarini, G., Povolo, M., Leardi, R., & Toppino, P. (1997). Influence of heat treatment on the volatile compounds of milk. *Journal of Agricultural Chemistry, 45*, 3171–3177.

Council Regulation (EC) 2597/97 of 18 December 1997 laying down additional rules on the common organization of the market in milk and milk products for drinking milk. *Official Journal of the European Union, L351*, 13.

Dalton, C. B., Austin, C. C., Sobel, J., Hayes, P. S., Bibb, W. F., Graves, L. M., et al. (1997). An outbreak of gastroenteritis and fever due to *Listeria monocytogenes* in milk. *The New England Journal of Medicine, 336*, 100–105.

D'Aoust, J. Y. (1989). Manufacture of dairy products from unpasteurized milk: a safety assessment. *Journal of Food Protection, 52*, 906–914.

De Buyser, M. L., Dufour, B., Maire, M., & Lafarge, V. (2001). Implication of milk and milk products in food-borne diseases in France and in different industrialized countries. *International Journal of Food Microbiology, 67*, 1–17.

Deeth, H. (2006). Lipoprotein lipase and lipolysis in milk. *International Dairy Journal, 16*, 555–562.

De Louvois, J., & Rampling, A. (1998). One fifth of samples of unpasteurised milk are contaminated with bacteria. *British Medical Journal, 316*, 625.

Demott, B. J., & Praepanitchai, O. A. (1978). Influence of storage, heat, and homogenization upon xanthine oxidase activity of milk. *Journal of Dairy Science, 61*, 164–167.

De Reu, K., Grijspeerdt, K., & Herman, L. (2004). A Belgian survey of hygiene indicator bacteria and pathogenic bacteria in raw milk and direct marketing of raw milk farm products. *Journal of Food Safety, 24*, 17–36.

Desmasures, N., Bazin, F., & Guéguen, M. (1997). Microbiological composition of raw milk from selected farms in the Camembert region of Normandy. *Journal of Applied Microbiology, 83*, 53–58.

Dewettinck, K., Rombout, R., Thienpont, N., Trung, T., Messens, K., & Van Camp, J. (2008). Nutritional and technological aspects of milk fat globule membrane material. *International Dairy Journal, 18*, 436–457.

Domínguez Rodriguez, L., Fernández Garayzabal, J. F., Vazquez Boland, J. A., Rodriguez Ferri, E., & Suarez Fernández, G. (1985). Isolation of micro-organisms of the species *Listeria* from raw milk intended for human consumption. *Canadian Journal of Microbiology, 31*, 938–941.

Douglas, F., Greenberg, R., & Farrell, H. M. (1981). Effects of ultra-high-temperature pasteurization on milk proteins. *Journal of Agricultural and Food Chemistry, 29*, 11–15.

Ebringer, L., Ferenčik, M., & Krajčovič, J. (2008). Beneficial health effects of milk and fermented dairy products – review. *Folia Microbiologica, 53*, 378–394.

EFSA – European Food Safety Authority. (2009a). The community summary report on trends and sources of zoonoses and zoonotic agents in the European Union in 2007. *The EFSA Journal, 233*, 313. <http://www.efsa.europa.eu/fr/efsajournal/doc/223r.pdf>.

EFSA – European Food Safety Authority. (2009b). Review of the potential health impact of β-casomorphins and related peptides 1. Report of the DATEX Working Group on β-casomorphins (question N° EFSA-Q-2008-379). *EFSA Scientific Report, 231*, 1–107. <http://www.efsa.europa.eu/en/efsajournal/doc/231r.pdf>.

EFSA – European Food Safety Authority. (2010). The community summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in the European Union in 2008. *EFSA Journal, 8*(1496), 410. <http://www.efsa.europa.eu/en/scdocs/doc/1496.pdf>.

Ehn, B. M., Ekstrand, B., Bengtsson, U., & Ahlstedt, S. (2004). Modification of IgE binding during heat processing of the cow's milk allergen beta-lactoglobulin. *Journal of Agricultural and Food Chemistry, 52*, 1398–1403.

European Parliament. (2001). Written question E-2907/00. Subject: homogenised milk. *Official Journal of the European Communities, 44*, 127. <http://eur-lex.europa.eu/JOHtml.do?uri=OJ: C:2001:136E: SOM:EN: HTML>.

European Parliament. (2002). Written question E-0864/02. Subject: possible harmful effects of xanthine oxidase in milk. *Official Journal of the European Communities, 45*, 227. <http://eur-lex.europa.eu/JOHtml.do?uri=OJ: C:2002:205E: SOM:EN: HTML>.

Farkye, N. Y., & Imafidon, G. I. (1995). Thermal denaturation of indigenous milk enzymes. In P. F. Fox (Ed.), *Heat-induced changes in milk* (2nd ed.) (pp. 331–348.) Brussels: International Dairy Federation.

Fassa, P. (2010). Pasteurized milk: beware of the deadly issues, part I. NaturalNews.com (website). <http://www.naturalnews.com/z028799_pasteurized_milk_raw.html>.

Favé, G., Coste, T., & Armand, M. (2004). Physicochemical properties of lipids: new strategies to manage fatty acid bioavailability. *Cellular and Molecular Biology, 50*, 815–831.

FDA – Food and Drug Administration. (2005). Presentation: "on the safety of raw milk (with a word about pasteurization)". Leonard C. & Sheehan J., November 3, 2005, presented to 2005 NCIMS. <http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/MilkSafety/ConsumerInformationAboutMilkSafety/ucm165105.htm>.

FDA – Food and Drug Administration. (2011). *Grade "A" pasteurized milk ordinance*. Revision 2011. U.S. Department of Health and Human Services, Public Health Service, FDA. <http://www.fda.gov/Food/FoodSafety/Product-SpecificInformation/MilkSafety/DairyGradeAVoluntaryHACCP/default.htm>.

Fenlon, D. R., Stewart, T., & Donachie, W. (1995). The incidence, numbers and types of *Listeria monocytogenes* isolated from farm bulk tank milks. *Letters in Applied Microbiology, 20*, 57–60.

Fenlon, D. R., & Wilson, J. (1989). The incidence of *Listeria monocytogenes* in raw milk from farm bulk tanks in north-east Scotland. *Journal of Applied Bacteriology, 66*, 191–196.

Fleming, D., Cochi, S. L., MacDonald, K. L., Brondum, J., Hayes, P. S., Plikaytis, B. D., et al. (1985). Pasteurized milk as a vehicle of infection in an outbreak of listeriosis. *The New England Journal of Medicine, 312*, 404–407.

Fox, P. F., & Kelly, A. L. (2006). Review: indigenous enzymes in milk: overview and historical aspects – part 1 & 2. *International Dairy Journal, 16*, 500–532.

Fox, P. F., & McSweeney, P. L. H. (2006). *Lipids* (3rd ed.) (p. 801). In *Advanced dairy chemistry, Vol. 2*. New York: Springer Science + Business Media, Inc.

Galbraith, N. S., Forbes, P., & Clifford, C. (1982). Communicable disease associated with milk and dairy products in England and Wales 1951–80. *British Medical Journal, 284*, 1761–1765.

Gehring, U., Spithoven, J., Schmid, S., Bitter, S., Braun-Fahrländer, C., Dalhin, J. C., et al. (2008). Endotoxin levels in cow's milk samples from farming and non-farming families – the PASTURE study. *Environment International, 34*, 1132–1136.

German, J. B., & Dillard, C. J. (2006). Composition, structure and absorption of milk lipids: a source of energy, fat-soluble nutrients and bioactive molecules. *Critical Reviews in Food Science and Nutrition, 46*, 57–92.

Gille, D. (2009). Die Homogenisierung der Milch – eine Gesundheitsgefährdung? [Potential health risk from homogenization of milk?] *Lebensmittelindustrie und Milchwirtschaft, 130*, 20–22.

Gillespie, I. A., Adak, G. K., O'Brien, S. J., & Bolton, F. J. (2003). Milkborne general outbreaks of infectious intestinal disease, England and Wales, 1992–2000. *Epidemiology & Infection, 130*, 461–468.

Gopal, P. K., & Gill, H. S. (2000). Oligosaccharides and glycoconjugates in bovine milk and colostrums. *British Journal of Nutrition, 84*, S69–S74.

Greenwood, M. H., Roberts, D., & Burden, P. (1991). The occurrence of *Listeria* species in milk and dairy products: a national survey in England and Wales. *International Journal of Food Microbiology, 12*, 197–206.

Griffiths, M. W. (1986). Use of milk enzymes as indices of heat treatment. *Journal of Food Protection, 49*, 696–705.

Griffiths, M. W. (2010). *Milk production and processing*In *Improving the safety and quality of milk, Vol. 1.* (p. 520). Guelph: Woodhead Publishing Limited.

Guéguen, L., & Pointillart, A. (2000). The bioavailability of dietary calcium. *Journal of the American College of Nutrition, 19*, 119S–136S.

Hahn, G., Walte, H. G., Coenen, C., & Teufel, P. (1999). Direct marketing of raw milk: findings and risk consideration. *Kieler Milchwirtschaftliche Forschungsberichte, 51*, 105–115.

Harvey, J., & Gilmour, A. (1992). Occurrence of *Listeria* species in raw milk and dairy products produced in Northern Ireland. *Journal of Applied Bacteriology, 72*, 119–125.

Haug, A., Høstmark, A., & Harstad, O. (2007). Bovine milk in human nutrition – a review. *Lipids in Health and Disease, 6*(25).

Headrick, M. L., Korangy, S., Bean, N. H., Angulo, F. J., Altekruse, S. F., Potter, M. E., et al. (1998). The epidemiology of raw milk-associated foodborne disease outbreaks reported in the United States, 1973 through 1992. *American Journal of Public Health, 88*, 1219–1221.

Heuvelink, A. E., Bleumink, B., van den Biggelaar, F. L., Te Giffel, M. C., Beumer, R. R., & De Boer, E. (1998). Occurrence and survival of verocytotoxin-producing *Escherichia coli* O157 in raw cow's milk in the Netherlands. *Journal of Food Protection, 61*, 1597–1601.

Ho, C. Y., & Clifford, A. J. (1976). Digestion and absorption of bovine milk xanthine oxidase and its role as an aldehyde oxidase. *Journal of Nutrition, 106*, 1600–1609.

van Hooijdonk, A. C. M., Kussendrager, K. D., & Steijns, J. M. (2000). *In vivo* antimicrobial and antiviral activity of components in bovine milk and colostrum involved in non-specific defence. *British Journal of Nutrition, 84*, S127–S134.

Humphrey, T. J., & Hart, R. J. (1988). *Campylobacter* and *Salmonella* contamination of unpasteurized cows' milk on sale to the public. *Journal of Applied Bacteriology, 65*, 463–467.

Ishibashi, N., & Yamazaki, S. (2001). Probiotics and safety. *The American Journal of Clinical Nutrition, 73*, 465S–470S.

Jensen, R. (2002). Invited review: the composition of bovine milk lipids: January 1995 to December 2000. *Journal of Dairy Science, 85*, 295–350.

Jørgensen, H. J., Mathisen, T., Løvseth, A., Omoe, K., Qvale, K. S., & Loncarevic, S. (2005). An outbreak of staphylococcal food poisoning caused by enterotoxin H in mashed potato made with raw milk. *FEMS Microbiology Letters, 252*, 267–272.

Jouve, J. L., & Lahellec, C. (1991). Incidence des *Listeria* dans les denrées alimentaires. In *Proceedings on the international conference Listeria and food safety* (pp. 89–104). Laval: ASEPT.

Kilpeläinen, M., Terho, E. O., Helenius, H., & Koskenvuo, M. (2000). Farm environment in childhood prevents the development of allergies. *Clinical and Experimental Allergy, 30*, 201–208.

Kilshaw, P., Heppell, L., & Ford, E. (1982). Effects of heat treatment of cow's milk and whey on the nutritional quality and antigenic properties. *Archives of Disease in Childhood, 57*, 842–847.

Korhonen, H., Marnila, P., & Gill, H. S. (2000). Milk immunoglobulins and complement factors. *British Journal of Nutrition, 84*, S75–S80.

Korhonen, H., Pihlanto-Leppälä, A., Rantamäki, P., & Tupasela, T. (1998). Impact of processing on bioactive proteins and peptides. *Trends in Food Science & Technology, 9*, 307–319.

Lacroix, M., Léonil, J., Bos, C., Henry, G., Airinei, G., Fauquant, J., et al. (2006). Heat markers and quality indexes of industrially heat-treated [15N] milk protein measured in rats. *Journal of Agricultural and Food Chemistry, 54*, 1508–1517.

Langer, A. J., Ayers, T., Grass, J., Lynch, M., Angulo, F. J., & Mahon, B. E. (2012). Nonpasteurized dairy products, disease outbreaks, and state laws – United States, 1993–2006. *Emerging Infectious Diseases, 18*, 385–391.

Lee, M. B., & Middleton, D. (2003). Enteric illness in Ontario, Canada, from 1997 to 2001. *Journal of Food Protection, 66*, 953–961.

LeJeune, J. T., & Rajala-Schultz, P. J. (2009). Food safety: unpasteurized milk: a continued public health threat. *Clinical Infectious Diseases, 48*, 93–100.

Lewis, M. J., & Deeth, H. C. (2009). Heat treatment of milk. In A. Y. Tamime (Ed.), *Milk processing and quality management* (pp. 168–204). West Sussex: Blackwell Publishing Ltd.

Li, T., Tao, J., & Hong, F. (2005). Study on the inhibition effect of nisin. *The Journal of American Science, 1*, 33–37.

Li-Chan, E., Kummer, A., Losso, J. N., Kitts, D. D., & Nakai, S. (1995). Stability of bovine immunoglobulins to thermal treatment and processing. *Food Research International, 28*, 9–16.

Loss, G., Apprich, S., Waser, M., Kneifel, W., Genuneit, J., Büchele, G., et al. (2011). The protective effect of farm milk consumption on childhood asthma and atopy: the GABRIELA study. *Journal of Allergy and Clinical Immunology, 128*, 766–773.

Lund, B. M., & O'Brien, S. J. (2011). The occurrence and prevention of foodborne disease in vulnerable people. *Foodborne Pathogens and Disease, 8*, 961–973.

Marinez, B., Bravo, D., & Rodriguez, A. (2005). Consequences of the development of nisin-resistant *Listeria monocytogenes* in fermented dairy products. *Journal of Food Protection, 68*, 2383–2388.

Marks, N. E., Grandison, A. S., & Lewis, M. J. (2001). Challenge testing of the lactoperoxidase system in pasteurized milk. *Journal of Applied Microbiology, 91*, 735–741.

Martín, M. J., Martín-Sosa, S., & Hueso, P. (2002). Binding of milk oligosaccharides by several enterotoxigenic *Escherichia coli* strains isolated from calves. *Glycoconjugate Journal, 19*, 5–11.

Massa, S., Goffredo, E., Altieri, C., & Natola, K. (1999). Fate of *Escherichia coli* O157:H7 in unpasteurized milk stored at 8 degrees C. *Letters in Applied Microbiology, 28*, 89–92.

Mattila-Sandholm, T., & Saarela, M. (2003). *Functional dairy products, Vol. 1*. New York: CRC, (p. 416).

McKee, R., Madden, R. H., & Gilmour, A. (2003). Occurrence of verocytotoxin-producing *Escherichia coli* in dairy and meat processing environments. *Journal of Food Protection, 66*, 1576–1580.

McSweeney, P. L. H., & Fox, P. F. (2009). *Lactose, water, salts and minor constituents*. In *Advanced dairy chemistry, Vol. 3*. (3rd ed.) (p.806). New York: Springer-Verlag.

Mechie, S. C., Chapman, P. A., & Siddons, C. A. (1997). A fifteen month study of *Escherichia coli* O157:H7 in a dairy herds. *Epidemiology & Infection, 118*, 17–25.

Messelhäusser, U., Beck, H., Gallien, P., Schalchl, B., & Busch, U. (2008). Presence of shiga toxin-producing *Escherichia coli* and thermophilic *Campylobacter* spp. in cattle, food and water sources on Alpine pastures in Bavaria. *Archiv für Lebensmittelhygiene, 59*, 103–106.

Meyer-Broseta, S., Diot, A., Bastian, S., Rivière, J., & Cerf, O. (2003). Estimation of low bacterial concentration: *Listeria monocytogenes* in raw milk. *International Journal of Food Microbiology, 80*, 1–15.

Michalski, M. C. (2007). On the supposed influence of milk homogenization on the risk of CVD, diabetes and allergy. *British Journal of Nutrition, 97*, 598–610.

Michalski, M. C., & Januel, C. (2006). Does homogenization affect the human health properties of cow's milk? *Trends in Food Science & Technology, 17*, 423–437.

Murphy, M., Buckley, J. F., Whyte, P., O'Mahony, M., Anderson, W., Wall, P. G., et al. (2007). Surveillance of dairy production holdings supplying raw milk to the farmhouse cheese sector for *Escherichia coli* O157, O26 and O111. *Zoonoses and Public Health, 54*, 358–365.

O'Brien, J. (1995). Heat-induced changes in lactose: isomerization, degradation, Maillard browning. In P. F. Fox (Ed.), *Heat-induced changes in milk* (2nd ed.) (pp. 134–170). Brussels: International Dairy Federation.

Olano, A., & Martinez-Castro, I. (1989). Modification & interactions of lactose. *Bulletin of the International Dairy Federation, 238*, 35–44.

Oliver, S. P., Boor, K. J., Murphy, S. C., & Murinda, S. E. (2009). Food safety hazards associated with consumption of raw milk. *Foodborne Pathogens and Disease, 6*, 793–806.

Oliver, S. P., Jayarao, B. M., & Almeida, R. A. (2005). Foodborne pathogens in milk and the dairy farm environment: food safety and public health implications. *Foodborne Pathogens and Disease, 2*, 115–129.

Oosterom, J., Engels, G. B., Peters, R., & Pot, R. (1982). *Campylobacter jejuni* on cattle and raw milk in the Netherlands. *Journal of Food Protection, 45*, 1212–1213.

Organic Pastures. (2008). Living foods for life: fresh raw & cultured dairy & living foods (website). http://www.organicpastures.com.

Özkalp, B., Özden, B., Tuncer, Y., Sanlibaba, P., & Akçelik, M. (2007). Technological characterization of wild-type *Lactococcus lactis* strains isolated from raw milk and traditional fermented milk products in Turkey. *Lait, 87*, 521–543.

Panesar, P. S., Kumari, S., & Panesar, R. (2010). Potential applications of immobilized β-galactosidase in food processing industries. *Enzyme Research*16, art. ID 473137.

Paulsson, M. A., Svensson, U., Kishore, A. R., & Naidu, A. S. (1993). Thermal behavior of bovine lactoferrin in water and its relation to bacterial interaction and antibacterial activity. *Journal of Dairy Science, 76*, 3711–3720.

Perkin, M. R., & Strachan, D. P. (2006). Which aspects of the farming lifestyle explain the inverse association with childhood allergy? *Journal of Allergy and Clinical Immunology, 117*, 1374–1381.

Raw-milk-facts.com. (2008). *Not all raw milk is the same!* White Tiger Productions (website). http://www.raw-milk-facts.com/About_Raw_Milk.html.

Raynaud, S., Boscher, P., Picant, P., Mathieu, B., Degand, C., Poutreil, B., et al. (2006). Prévalence, origine, circulation et persistence des *Escherichia coli* producteurs de shiga-toxines (STEC) dans les élevages bovins français. *Bulletin Épidémiologique, 21*, 1–3.

Rea, M. C., Cogan, T. M., & Tobin, S. (1992). Incidence of pathogenic bacteria in raw milk in Ireland. *Journal of Applied Bacteriology, 73*, 331–336.

Regulation (EC) 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. *Official Journal of the European Communities, L31*, 1–24.

Regulation (EC) 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for on the hygiene of foodstuffs. *Official Journal of the European Union, L139*, 55.

Ribbens, S., De Bleecker, K., Demeulemeester, L., Van Crombrugge, J., Stoop, S., Mijten, E., et al. (2010). Serosurvey for Q-fever, *Neosporosis*, *Salmonellosis* and *Leptospira* in Northern-Belgian dairy herds. In *Proceedings of the XXVI world Buiatrics congress*, Santiago, Chile, November 14–18, 2010 (p. 779).

Riedler, J., Braun-Fahrländer, C., Eder, W., Schreuer, M., Waser, M., Maisch, S., et al. (2001). Exposure to farming in early life and development of asthma and allergy: a cross-sectional survey. *Lancet, 358*, 1129–1133.

Rodler, M., & Körbler, W. (1989). Examination of *Listeria monocytogenes* in milk products. *Acta Microbiologica et Immunologica Hungarica, 36*, 259–261.

Roth-Walter, F., Berin, M. C., Arnaboldi, P., Escalante, C. R., Dahan, S., Rauch, J., et al. (2008). Pasteurization of milk proteins promotes allergic sensitization by enhancing uptake through Peyer's patches. *Allergy, 63*, 882–890.

Sanaa, M. (1993). *Epidémiologie de la contamination du lait à la ferme par Listeria monocytogenes* (p. 207). Thèse de doctorat, Université Paris XI, Paris.

Schaafsma, G. (1989). Effects of heat treatment on the nutritional value of milk. *Bulletin of the International Dairy Federation, 238*, 68–70.

Schaafsma, G. (2008). Review: lactose and lactose derivatives as bioactive ingredients in human nutrition. *International Dairy Journal, 18*, 458–465.

Schanbacher, F. L., Talhouk, R. S., & Murray, F. A. (1997). Biology and origin of bioactive peptides in milk. *Livestock Production Science, 50*, 105–123.

Schouten, J. M., Graat, E. A., Frankena, K., van de Giessen, A. W., van der Zwaluw, W. K., & de Jong, M. C. (2005). A longitudinal study of *Escherichia coli* O157 in cattle of a Dutch dairy farm and in the farm environment. *Veterinary Microbiology, 107*, 193–204.

Schuchat, A., Swaminathan, B., & Broome, C. V. (1991). Epidemiology of human listeriosis. *Clinical Microbiology Reviews, 4*, 169–183.

Shwimmer, A., Freed, M., Blum, S., Khatib, N., Weissblit, L., Friedman, S., et al. (2007). Mastitis caused by *Yersinia pseudotuberculosis* in Israeli dairy cattle and public health implications. *Zoonoses and Public Health, 54*, 353–357.

Solomakos, N., Govaris, A., Angelidis, A. S., Pournaras, S., Burriel, A. R., Kritas, S. K., et al. (2009). Occurrence, virulence genes and antibiotic resistance of *Escherichia coli* O157 isolated from raw bovine, caprine and ovine milk in Greece. *Food Microbiology, 26*, 865–871.

Souci, S. W., Fachmann, W., & Kraut, H. (2008). *Food composition and nutrition tables* (7th ed.) (p. 1364). Stuttgart: Wissenschaftliche Verlagsgesellschaft mbH.

Spreer, E. (1998). *Milk and dairy product technology* (p. 483). Dresden: Marcel Dekker Inc.

Stabel, J., Pearce, L., Chandler, R., Hammer, P., Klijn, N., Cerf, O., et al. (2001). Destruction by heat of *Mycobacterium paratuberculosis* in milk and milk products. *Bulletin of the International Dairy Federation, 362*, 53–61.

Steijns, J. M., & van Hooijdonk, A. C. M. (2000). Occurrence, structure, biochemical properties and technological characteristics of lactoferrin. *British Journal of Nutrition, 84*, S11–S17.

Stephan, R., & Bühler, K. (2001). A survey of the prevalence of *Escherichia coli* 0157 and other Shigatoxin-producing *Escherichia coli* in bulk-tank milk samples from north-east Switzerland. *Archiv für Lebensmittelhygiene, 52*, 122–123.

Stephan, R., & Bühler, K. (2002). Prévalence de *Campylobacter* spp., *Salmonella* spp. et *Listeria monocytogenes* dans des échantillons de lait de tank de stockage du Nord-Est de la Suisse. *Archiv für Lebensmittelhygiene, 53*, 62–65.

Stevens, C. R., Millar, T. M., Clinch, J. G., Kanczler, J. M., Bodamyali, T., & Blake, D. R. (2000). Antibacterial properties of xanthine oxidase in human milk. *The Lancet, 356*, 829–830.

Svenning, C., Brynhildsvold, J., Molland, T., Langsrud, T., & Vegarud, G. (2000). Antigenic response of whey proteins and genetic variants of β-lactoglobulin – the effect of proteolysis and processing. *International Dairy Journal, 10*, 699–711.

Tambekhar, D., & Bhutada, S. (2010). Studies on antimicrobial activity and characteristics of bacteriocins produced by *Lactobacillus* strains isolated from milk of domestic animals. *The Internet Journal of Microbiology, 8*(12). http://www.ispub.com/journal/the_internet_journal_of_microbiology.html.

Touch, V., & Deeth, H. C. (2009). Microbiology of raw and market milks. In A. Y. Tamime (Ed.), *Milk processing and quality management* (pp. 48–71). West Sussex: Blackwell Publishing Ltd.

Vereta, L. A., Skorobrekha, V. Z., Nikolaeva, S. P., Aleksandrov, V. I., Tolstonogova, V. I., Zakharycheva, T. A., et al. (1991). The transmission of the tick-borne encephalitis virus via cow's milk. *Med Parazitol (Mosk), 3*, 54–56.

Vernozy-Rozand, C., & Roze, S. (2003). *Bilan des connaissances relatives aux Escherichia coli producteurs de Shiga-toxines (Afssa report)* (p. 221). Paris: Afssa. http://lesrapports.ladocumentationfrancaise.fr/BRP/054000089/0000.pdf.

Villani, F., Aponte, M., Blaiotta, G., Mauriello, G., Pepe, O., & Moschetti, G. (2001). Detection and characterization of a bacteriocin, garviecin L1-5, produced by *Lactococcus garvieae* isolated from raw cow's milk. *Journal of Applied Microbiology, 90*, 430–439.

Vogt, R. L., Donnelly, C., Gellin, B., Bibb, W., & Swaminathan, B. (1990). Linking environmental and human strains of *Listeria monocytogenes* with isoenzyme and ribosomal RNA typing. *European Journal of Epidemiology, 6*, 229–230.

Waak, E., Tham, W., & Danielsson-Tham, M. L. (2002). Prevalence and fingerprinting *of Listeria monocytogenes* strains isolated from raw whole milk in farm bulk tanks and in dairy plant receiving tanks. *Applied and Environmental Microbiology, 68*, 3366–3370.

Walstra, P., Geurts, T. J., Noomen, A., Jellema, A., & Van Boekel, M. A. J. S. (1999). *Dairy technology, principles of milk properties and processes*. New York: Marcel Dekker, Inc.

Walstra, P., & Jeness, R. (1984). *Dairy chemistry and physics* (p. 467). New York: John Wiley & Sons.

Waser, M., Michels, K. B., Bieli, C., Flöistrup, H., Pershagen, G., Von Mutius, E., et al. (2007). Inverse association of farm milk consumption with asthma and allergy in rural and suburban populations across Europe. *Clinical & Experimental Allergy, 37*, 661–670.

Wasmuth, H. E., & Kolb, H. (2000). Cow's milk and immune-mediated diabetes. *Proceedings of the Nutrition Society, 59*, 573–579.

Weeks, C. E., & King, R. L. (1985). Bioavailability of calcium in heat-processed milk. *Journal of Food Science, 50*, 1101–1105.

Wickens, K., Lane, J. M., Fitzharris, P., Siebers, R., Riley, G., Douwes, J., et al. (2002). Farm residence and exposures and the risk of allergic diseases in New Zealand children. *Allergy, 57*, 1171–1179.

Williamson, S., Finucane, E., Ellis, H., & Gamsu, H. R. (1978). Effect of heat treatment of human milk on absorption of nitrogen, fat, sodium, calcium, and phosphorus by preterm infants. *Archives of Disease in Childhood, 53*, 555–563.

Zabbia, A., Buys, E. M., & De Kock, H. L. (2012). Undesirable sulphur and carbonyl flavor compounds in UHT milk: a review. *Critical Reviews in Food Science and Nutrition, 52*, 21–30.

Zucht, H. D., Raida, M., Adermann, K., Mägert, H. J., & Forssmann, W. G. (1995). Casocidin-I: a casein-alpha s2 derived peptide exhibits antibacterial activity. *FEBS Letters, 372*, 185–188.

Zurera-Cosano, G., Moreno-Rojas, R., & Amaro-Lopez, M. (1994). Effect of processing on contents and relationships of mineral elements of milk. *Food Chemistry, 51*, 75–78.