PHO Technical Report:

Update on Raw Milk Consumption and Public Health

A Scientific Review for Ontario Public Health Professionals

Prepared by

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February, 2013

Public Health Ontario
PARTNERS FOR HEALTH

Santé publique Ontario
PARTENAIRES POUR LA SANTÉ

How to cite this document:
Ontario Agency for Health Protection and Promotion (Public Health Ontario). PHO technical report: Update on raw milk consumption and public health: A scientific review for Ontario public health professionals. Toronto, ON: Queen's Printer for Ontario; 2013.

ISBN: 978-1-4606-1039-8

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Published by the Ontario Agency for Health Protection and Promotion

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www.oahpp.ca

Acknowledgements

The first draft of this report was informed by peer review by internal Public Health Ontario infectious disease and environmental health experts. A revised draft report was then circulated for scientific comment from key stakeholders in Ontario public health units, the Ontario Ministry of Agriculture, Food and Rural Affairs, and the Ontario Ministry of Health and Long-Term Care for the purposes of informing the final version of this report. We gratefully acknowledge these reviewers for their valuable contributions to this report.

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Executive summary

This technical report was created to serve as a resource for Ontario public health professionals, further to a request from the Office of the Chief Medical Officer of Health. Public Health Ontario (PHO) staff within Infectious Diseases, Environmental and Occupational Health, and Public Health Ontario Laboratories (PHOL) developed the technical report to summarize the available scientific evidence relating to raw milk consumption and public health.

The report highlights relevant background information, and describes the methods and findings of a review of the recent scientific literature applicable to the Ontario context addressing contamination of raw milk (e.g., microbiological and non-microbiological); consumption of raw milk and human illness; selected possible benefits of raw milk consumption and/or harms of milk pasteurization; and portable testing methods to identify raw milk. A summary of key review findings follows.

Contamination of raw milk

- Numerous recent bulk tank studies from the United States have identified the presence of human pathogens in raw milk. Pathogens have included *Listeria monocytogenes, Salmonella* spp., *Campylobacter jejuni, Yersinia enterocolitica* and *Escherichia* coli O157:H7.
- Several recent Ontario bulk tank studies have identified the presence of multiple human pathogens (i.e., *L. monocytogenes, Campylobacter* spp. and verotoxigenic *E. coli, Coxiella burnetii*) in raw milk from Ontario cows, goats and/or sheep.
- The most recent Ontario surveys testing raw milk from licensed dairy farms for environmental contaminants demonstrated few residual levels above established limits.
- There are no routinely collected data on microbiological or non-microbiological (e.g., environmental/ chemical) contaminants in raw milk from non-registered dairy producers (farmers) in Ontario. These dairy producers operate outside of the regulated system, which conducts routine monitoring of licensed dairy producers in Ontario and therefore may not be identifiable or accessible for monitoring.
- The literature suggests that pasteurization does not alter the presence of chemical contaminants in milk.

Human illness following raw milk consumption

- In jurisdictions similar to Ontario, in terms of dairy industry practices the recent scientific literature has repeatedly demonstrated laboratory evidence of indistinguishable pulsed field gel electrophoresis (PFGE) patterns from human isolates and from raw milk samples from product consumed before illness onset, providing evidence that supports a causal relationship between raw milk consumption and human illness.
    - Recent epidemiological studies have also demonstrated statistical associations between consumption of raw milk and subsequent infectious disease occurrence.
    - One recent review concluded that evidence linking raw milk consumption to human illness is strongest for *E. coli*, *Campylobacter* spp. and *Salmonella* spp.

- Recent public health surveillance data from the United States, Australia and Ontario have identified consumption of raw milk or raw milk products as an exposure preceding illness onset in reported infectious disease cases and outbreaks.
    - Ontario notifiable disease data have significant limitations for describing the burden of raw milk-associated illness in Ontario and likely underreport exposures and associated cases.
    - These limitations notwithstanding, consumption of raw milk or raw milk products before illness onset was reported for 256 confirmed cases of enteric and zoonotic diseases in Ontario (Jan. 1, 2005–Sept. 30, 2012).
    - More than half (52 per cent) of the reported cases occurred in infants and children up to 14 years of age.
    - Campylobacteriosis was the most commonly reported disease (69 per cent of cases), followed by cryptosporidiosis (11 per cent), salmonellosis (eight per cent), and verotoxin producing *E. coli* (five per cent).

Selected possible benefits of raw milk consumption and/or harms of milk pasteurization

- The literature reviewed suggests a possible association between consumption of raw milk and decreased incidence of childhood atopy, hay fever and asthma. This association may be due to confounders (e.g., other exposures in farm settings) or to bias related to the design of observational studies (e.g., parents of children with asthma may recall raw vs. heat-treated milk consumption differently than parents of children without asthma). The literature reviewed did not identify mechanisms for a possible protective effect of raw milk.
- The literature reviewed suggests that heat treatment processes such as pasteurization can alter the structure of certain milk proteins. The degree to which this may contribute to clinical milk allergies and the mechanism by which heat treatment may affect the allergenicity of milk proteins is not fully understood. In addition, our review identified some inconsistent findings about the direction of the association between heat treatment and allergenicity of milk, as some studies suggest a link between heat treatment and decreased allergenicity of milk. Our review did not identify any reported cases of milk allergies attributed to altered milk proteins.
- A systematic review found some evidence that pasteurization decreased the concentrations of vitamins B12 and E; increased vitamin A and was not associated with a statistically significant difference in vitamin B6 concentration in milk. However, the effect of pasteurization on milk's nutritive value was considered minimal because milk is not viewed as an important dietary source of these vitamins.

Portable testing methods to identify raw milk

- As of August, 2012, our literature review did not identify any described or evaluated portable tests that could be used to assess the adequacy of milk pasteurization (i.e., to detect the presence of raw milk) in the field without minimal laboratory resources.

Abbreviations

ALP	Alkaline phosphatase
CDC	U.S. Centers for Disease Control and Prevention
CFIA	Canadian Food Inspection Agency
CPHA	Canadian Public Health Association
DFO	Dairy Farmers of Ontario
EPAS	Chemiluminescent Enzyme Photo-Activated Substrate
FDA	Food and Drugs Act
HPPA	Health Protection and Promotion Act
HUS	Hemolytic uremic syndrome
PHUs	Public health units
IBD	Inflammatory bowel disease
IDR	Incidence density ratio
iPHIS	Integrated Public Health Information System
Map	Mycobacterium avium paratuberculosis
MOHs	Ontario medical officers of health
MOHLTC	Ontario Ministry of Health and Long-term Care
MRL	Maximum Residue Limits
NCRMP	The National Chemical Residue Monitoring Program
ODC	Ontario Dairy Council
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
PAH	Polyaromatic hydrocarbons
PCB	Polychlorinated biphenyl
PFGE	Pulsed field gel electrophoresis
PHIs	Public health inspectors
PHO	Public Health Ontario
PHOL	Public Health Ontario Laboratories
SCC	Somatic cell count

Glossary

For the purposes of this report, the following definitions were used.

A **bulk tank** is a large storage tank, usually made of stainless steel, for cooling and holding raw milk from individual animals (e.g., cows, does, ewes). The bulk tank serves the purpose of agitating and storing the milk on the farm at an appropriate temperature until the milk is collected for transportation to the milk processing plant.

A **milk filter** serves the purpose of filtering large particulate debris (e.g., straw or hay particles) that may inadvertently enter milk from the milking process. The filter is usually placed in the milk pipeline, which transports the milk from the animal to the bulk tank.

Pasteurization is a process of heating raw milk to a specific temperature for a predefined length of time and then immediately cooling it after it is removed from the heat. This process results in the destruction of harmful microorganisms and slows spoilage due to microbial growth in the food.[i,1]

Milk processing activities include a range of activities involved in the preparation of milk products for human consumption. Most milk processing activities (e.g., freezing, culturing) are used to change the physical properties of milk. Only pasteurization and sterilization using heat can be relied upon to provide a consistent and scientifically measurable level of pathogen reduction (i.e., serve as critical control points).

Raw milk is defined as fluid milk obtained from an animal [e.g., cow, doe (female goat) or ewe (female sheep)] that has not undergone any heat treatment.

Somatic cell count (**SCC**) is used as an indicator of the quality of raw milk (i.e., its suitability to make high-quality milk products). Somatic cells are primarily white blood cells (i.e., leukocytes). The number of somatic cells may increase as a result of udder infection (e.g., mastitis) or teat/udder injury and varies due to many factors, including the cow's age, lactation stage, season and stress.

Bulk tank SCC, or the herd averages of individual cow SCC results, are indicators of the state of udder health in the herd.[2] However, SCC does not test for specific human pathogens and is not used to determine the safety of milk for human consumption.

Sterilization is the process of heating raw milk for various time and temperature combinations that results in the destruction of all microorganisms. Sterilization serves the purpose of extending the shelf life of milk, and thus, relative to pasteurized milk, sterilized milk would have a longer shelf life.[ii,3]

[i] The Ontario *Health Protection and Promotion Act (HPPA)*, Regulation 562, section 42(1), defines pasteurization as 63° C for not less than 30 minutes or 72° C for not less than 16 seconds or a temperature and time combination that "will result in the equivalent destruction of pathogenic organisms and phosphatase."

[ii] The Ontario *HPPA*, Regulation 562, section 42(2), defines sterilization as heating to 135° C for not less than two seconds or "to such other temperature for such period of time that will result in sterilization."

Introduction

Purpose

This technical report was created to serve as a resource for Ontario public health professionals, further to a request from the Office of the Chief Medical Officer of Health. Public Health Ontario (PHO) staff within Infectious Diseases, Environmental and Occupational Health, and Public Health Ontario Laboratories (PHOL) developed the technical report to summarize the available scientific evidence relating to raw milk consumption and public health.

Objectives

The objectives of this technical report were to:

1. Provide background information relevant to the context of raw milk consumption and public health practice in Ontario.
2. Provide a review of the recent scientific literature to address the following questions:
    - Contamination of raw milk:
        - Is there any recent evidence that raw milk is contaminated by human pathogens in Ontario and similar North American jurisdictions?
        - Is there a difference in rates of chemical contaminants between raw milk and pasteurized milk?
        - What chemical contaminants have been found in milk in Ontario and comparable jurisdictions?
    - Consumption of raw milk and human illness:
        - Is there any recent evidence linking consumption of raw milk or raw milk products to human illness in Ontario and similar jurisdictions?
    - Selected possible benefits of raw milk consumption and/or harms of milk pasteurization:
        - Is there any evidence that raw milk is protective against developing childhood atopy, rhino/conjunctivitis and asthma?
        - Is there any evidence linking milk pasteurization to milk allergies?
        - Is there any evidence that pasteurization affects vitamins in milk?
- Portable testing methods to identify raw milk:
    - Is there any evidence to support portable methods to test for the presence of raw milk?

Background

Potential pathways of raw milk contamination

Pathogen reservoirs exist in the dairy farm environment. These reservoirs include milk-producing cows, goats, sheep or water buffalo; other animals, rodents, birds or insects; humans; and other natural and human-made elements of the farm environment.[4] Contamination of raw milk with routine colonizers or disease-causing microorganisms from one or more of these reservoirs is known to occur. In general, the three main sources of pre-processing contamination of milk are:

- inside of the udder (e.g., infection of the mammary gland or mastitis);
- the outside of the udder (e.g., skin flora or soiling of the udder with animal feces or human handling of the udder); and
- on-farm milking equipment (e.g., cleaned inadequately or with contaminated water, inadequately maintained).[5]

Other environmental factors influencing microbial contamination of raw milk include the temperature and duration of storage.[6]

Pathogens isolated from raw milk in the past include *Staphylococcus aureus*, *Campylobacter jejuni*, *Salmonella* spp.*, Escherichia coli* O157:H7*, Listeria monocytogenes, Mycobacterium tuberculosis, Mycobacterium bovis, Brucella* spp.*, Coxiella burnetii, Yersinia enterocolitica* and *Bacillus cereus.*[7]

Due to eradication programs initiated in the 1970s and ongoing notifiable animal disease surveillance, Canada and Ontario earned official bovine brucellosis-free status in 1985.[8] Ontario participates in monitoring for bovine brucellosis; for example, Ontario took part in the 2007/8 bovine serological survey, for which over 15,000 samples were collected across the country. This survey resulted in the conclusion that Canada remained free of bovine brucellosis, meaning that the prevalence of brucellosis was estimated (with a confidence level of 95 per cent) to be at or below a prevalence of 0.02 per cent.[9] Similarly, Canada adopted a bovine tuberculosis eradication program, and, based on federal slaughter surveillance, Ontario has been certified bovine tuberculosis-free since 1994.[10] Sporadic cases still occur; for example, in 2006, *M. bovis* was detected in an Ontario-farmed deer herd. The most likely source of infection was considered to be reactivation of latent infection in deer imported from New Zealand in the 1990s.[11]

There is also potential for chemical contaminants to be present in both raw and pasteurized dairy milk. Antibiotic and other veterinary drug residues can enter milk through their use on dairy cattle. Contaminants such as pesticides, dioxins, furans, polychlorinated biphenyl (PCB), polyaromatic hydrocarbons (PAH), other persistent organic pollutants may enter milk through agricultural practices or industrial pollution. Aflatoxin is a mycotoxin that may enter dairy cattle and their milk supply through contaminated feed and fodder. Metal and other elements may be present in milk from naturally occurring and anthropogenic sources. Although no major chemical contamination incidents involving the dairy milk supply have been reported in Ontario, milk-related chemical events of public health concern have occurred in other jurisdictions. For example, in the 1970s in Michigan, the accidental addition of polybrominated biphenyl, a flame retardant, to dairy feed resulted in widespread contamination of dairy milk and meat, and was linked to adverse health effects in exposed populations.[12]

Historical burden of disease attributed to raw milk consumption

In 1908, Toronto's Medical Officer of Health attributed at least 25 per cent of tuberculosis cases among children to the consumption of contaminated raw milk.[13] From 1926 through 1938, the provincial incidence of extrapulmonary tuberculosis of bovine origin in Ontario children was estimated to be 9.6 per cent.[14] Before widespread pasteurization, milk consumption was also linked to multiple infectious disease epidemics each year (1912–1939); the Canadian incidence of reported typhoid and paratyphoid fevers, scarlet fever and "septic sore throat" attributed to milk consumption was, on average, 12 outbreaks per year, involving about 1,500 cases and 130 deaths per year.[15] For example, a 1931 paratyphoid fever outbreak involving 457 cases and three deaths was reported in St. Catharines, Ont., among persons served by one dairy on a single milk route.[16] Similarly, in the early 20th century (i.e., the pre-pasteurization era), an estimated 25 per cent of the burden of foodborne illness in the United States was attributed to the consumption of contaminated milk.[17]

Regulatory context

Since 1938, Ontario law has prohibited the sale of raw (i.e., unpasteurized or unsterilized) milk for human consumption.[18] Since 1965, the *Milk Act* has regulated the sale of cow's and goat's milk and milk products in Ontario, and Section 15 of the *Milk Act* has required all milk processing premise operators and milk distributors to be licensed.[19] The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) is responsible for ensuring compliance with the *Milk Act*, including the licensing of dairy farms, milk processing premises and milk distributors.[20] There are approximately 4,000 licensed dairy cow farms and 250 registered dairy goat farms in Ontario, which are inspected on a regular basis to ensure compliance with the *Milk Act* and its regulations. Per the *Milk Act* Regulation 761, Section 35, only certified bulk tank milk graders can pick up and transport raw milk from a farm;[21] both graders and the trucks they use to transport raw milk are routinely inspected. A smaller number of sheep milk producers operate in Ontario but they are not regulated by the *Milk Act*. Please see Appendix A for an overview of OMAFRA's Dairy Food Safety Program, including the routine inspection and testing conducted in licensed farm premises, tank-trucks and dairy plants under the legislative framework of the *Milk Act*.

Section 18 of the *Health Protection and Promotion Act* (*HPPA*) also sets out requirements for unpasteurized or unsterilized milk (see below for the full text).[22]

HPPA Section 18: Unpasteurized or unsterilized milk[23]

(1) No person shall sell, offer for sale, deliver or distribute milk or cream that has not been pasteurized or sterilized in a plant that is licensed under the *Milk Act* or in a plant outside Ontario that meets the standards for plants licensed under the *Milk Act*. R.S.O. 1990, c. H.7, s. 18 (1).

Milk products

(2) No person shall sell, offer for sale, deliver or distribute a milk product processed or derived from milk that has not been pasteurized or sterilized in a plant that is licensed under the *Milk Act* or in a plant outside Ontario that meets the standards for plants licensed under the *Milk Act*. R.S.O. 1990, c. H.7, s. 18 (2).

Exception

(3) Subsection (1) does not apply in respect of milk or cream that is sold, offered for sale, delivered or distributed to a plant licensed under the *Milk Act*. R.S.O. 1990, c. H.7, s. 18 (3).

Definition

(4) In subsection (2),"milk product" means a product processed or derived in whole or mainly from milk. R.S.O. 1990, c. H.7, s. 18 (4).

The *HPPA* also gives Ontario medical officers of health (MOHs) and public health inspectors (PHIs) powers to investigate and intervene if a health hazard exists or may exist.[24] Section 13 of the *HPPA* empowers MOHs and PHIs to issue orders to take action(s) to "decrease the effect of or to eliminate" health hazards. The *HPPA* also identifies a list of reportable communicable diseases,[25] including disease caused by pathogens that have been isolated from raw milk. This legislation requires physicians, practitioners and laboratory operators (among others) to submit reports to the appropriate MOH, in respect of an individual who has or may have a reportable or communicable disease or an individual who is or may be infected with "an agent of a communicable disease."[26] On behalf of OMAFRA and/or the Ontario Ministry of Health and Long-Term Care (MOHLTC), the Ontario Ministry of Natural Resources may lead milk-related investigations and prosecutions.[27] At the federal level, the *Food and Drugs Act* (FDA) prohibits the sale of raw milk across Canada. [28] Certain animal diseases, including bovine tuberculosis and brucellosis, are federally notifiable diseases under the *Health of Animals Act*.[29] The Canadian Food Inspection Agency (CFIA) conducts routine surveillance and periodic surveys for these diseases.[30] The CFIA is responsible for monitoring the food supply for chemical residues and contaminants and enforcement of Maximum Residue Limits (MRL).[31] The National Chemical Residue Monitoring Program (NCRMP) is conducted annually by the CFIA and randomly tests raw milk from registered suppliers for veterinary drugs, mycotoxins, pesticides and metals.[31]

Of note, the *HPPA* does not prohibit the on-farm consumption of raw milk by farmers and their families. In addition, the *HPPA* does not prohibit the sale and distribution of raw milk cheeses, provided they have been made in a plant that is licensed under the *Milk Act* and aged for at least 60 days at a temperature not lower than 2° C.[22] The *FDA* also prohibits the sale of raw milk cheese unless it has been stored under legally defined conditions and sets microbiological standards (e.g., regarding *E.coli* and *S. aureus)* for raw milk cheeses.[32] As outlined in the Objectives section, the focus of this report is raw fluid milk, not raw milk cheese.

Routine raw milk testing practices in Ontario

The testing of raw milk samples in Ontario is a cooperative effort among OMAFRA, Dairy Farmers of Ontario (DFO) and the Ontario Dairy Council (ODC). Regulation 761 of the *Milk Act* requires routine testing of raw milk from licensed and registered cow and goat milk producers (farms) to assess its **quality** (i.e., its suitability to make high-quality milk products).[33,34] Bulk tank raw milk samples are tested for individual bacterial cell count, somatic cell count (SCC) and abnormal freezing point, which are indicators of milk quality (i.e., indicators of its suitability for making high-quality milk products, **not** its pathogenicity in humans or its safety for human consumption).[35,36] According to regulations under the *Milk Act*, the standards for Grade A raw milk include an aerobic colony count less than 50,000 cfu/mL and an SCC less than 400,000 scc/mL.[33,37] Results above prescribed thresholds result in penalties to be paid by the producers (farmers).[38] Although high SCC and bacterial cell counts are suggestive of contamination, low counts are not used to determine whether milk is safe for human consumption. Pathogen testing is not routinely performed, since raw milk from licensed/registered producers (farmers) is destined to undergo heat treatment (e.g., pasteurization) at licensed dairy processing facilities to remove human pathogens.

Raw milk samples from regulated producers (farmers) in Ontario also undergo routine **food safety testing** for substances that inhibit bacterial growth in raw milk (i.e., antibiotic residues). Per Regulation 761 of the *Milk Act*, OMAFRA retains responsibility for this raw milk food safety testing, including routine screening of raw milk samples conducted at the University of Guelph for an extensive range of residues in milk. While the *Milk*

Act does not stipulate that processors must screen incoming loads of milk for undesirable residues, the Dairy Establishment Inspection Manual (the national dairy inspection standard) mandates screening by processors of all loads of incoming milk. The DFO and the ODC have collaborated to implement a program whereby the majority of raw cow milk in Ontario is screened for inhibitors prior to the trucks unloading at the plant. As noted above, producers who ship contaminated milk face monetary penalties. In addition to this routine testing, OMAFRA also conducts periodic raw milk bulk tank pathogen prevalence surveys, as well as surveys to determine the prevalence of other environmental residues in raw milk (e.g., heavy metals, pesticides, dioxins, furans, PCBs, PAHs and aflatoxin).[39]

A similar monitoring system does not exist for (unlicensed) farm-gate sales of raw milk, and monitoring for compliance with the *Milk Act* is not possible for unlicensed/unregistered producers and distributors of raw milk (i.e., those of which OMAFRA / DFO is unaware or unable to access). In addition, non-cow or non-goat milk (e.g., sheep or buffalo milk) production, transport and processing operations are not regulated by the *Milk Act* and therefore are not subject to mandatory monitoring and compliance activities.

Testing methods for identification of raw milk

To determine the effectiveness of pasteurization of dairy products, the activity of the enzyme alkaline phosphatase (ALP) is measured.[40] ALP is destroyed or inactivated at a temperature slightly higher than the pasteurization temperature required to destroy the most resistant disease-causing organisms likely to be found in milk (e.g., *M. tuberculosis, M.bovis* and *C. burnetii*). In contrast, microbiological testing for the presence of bacteria will not prove that a sample of milk is raw.

When testing dairy products, the gold standard for determining effective pasteurization and absence of post-process contamination with raw milk is the Fluorophos test for ALP.[41,42] The Fluorophos test is the gold standard due to its high sensitivity and relative simplicity and can be completed within minutes to hours once received by a laboratory. The Fluorophos test is employed by both the PHOL and OMAFRA to detect raw milk in submitted samples (e.g., in the context of a health hazard investigation).[43] OMAFRA has adopted the U.S. and European Union standard fluorescence level of 350 mU/L or more as an indication of inadequate pasteurization. An additional actionable level of 100 mU/L triggers the investigation into potential causes for the higher than normal residual ALP levels. Other validated methods to measure residual ALP in pasteurized dairy products include the Modified Scharer colourimetric method and the Chemiluminescent Enzyme Photo-Activated Substrate (EPAS) method.[44]

Charm Sciences has developed a portable device to test for ALP (Fast-Alkaline Phosphatase). This device could be used in the field as a screening tool to determine whether a milk sample has been adequately pasteurized.[45] The device uses the Chemiluminescent EPAS method, in which a light reaction is detected and interpreted by a portable luminometer and test results are available within 45 seconds. This portable test has demonstrated promising preliminary results of comparable sensitivity and specificity to the laboratory based EPAS method. However, this device is not approved for use by Health Canada and therefore should not be used in Ontario.

Expert advice and advocacy against raw milk consumption

In early 20th-century Ontario, citizen advocates for children's health[46] and physicians at the Hospital for Sick Children[47] promoted mandatory pasteurization of milk out of concern for preventable infectious disease and death in children following consumption of raw milk. The Canadian Public Health Association (CPHA) and the

Canadian Medical Association also endorsed mandatory milk pasteurization, and the CPHA continues to view milk pasteurization as one of the great public health achievements of the 20th century.[48]

Currently, public health bodies including Health Canada and the U.S. Centers for Disease Control and Prevention (CDC) advise the public against consuming raw milk, citing its historical association with many serious diseases (e.g., bovine tuberculosis, brucellosis and typhoid) and its ongoing association with outbreaks of diseases caused by human pathogens that have been found in raw milk, including *Salmonella, E. coli* and *Listeria.* [49,50] These health organizations acknowledge that some individuals identify health benefits associated with drinking raw milk and/or health hazards associated with consuming pasteurized milk. However, they emphasize that consumption of raw milk has been linked to adverse health events including severe illness (e.g., meningitis or kidney failure), miscarriage and death; they advise that infants, young children, pregnant women, the elderly and immunocompromised individuals are at greater risk of becoming ill or severely ill after consuming raw milk. Overall, these health organizations view the risks of consuming raw milk as outweighing any possible benefits.[49,50] In addition, some citizen advocates view raw milk as a serious health hazard in Ontario and are actively raising awareness about this issue.[51]

Advocacy in support of raw milk sale and consumption

In early 20th-century Canada and Ontario, some advocates questioned the suitability of pasteurized milk for infants and children due to concerns that its vitamin content was altered. Some expressed concern that pasteurization would decrease other efforts to safeguard the milk supply (e.g., farm equipment hygiene).[52]

Currently, some advocacy groups and online communities active in Ontario view the ability to legally buy and sell raw milk as a rights/freedom-of-choice issue and view raw milk consumption as a healthy choice.[27] In 2005, an Ontario dairy farmer was charged with violating the *HPPA* and the *Milk Act* in relation to a cow-share operation. A Justice of the Peace rejected the charges,[27] but the Ontario Court of Justice subsequently convicted the farmer of multiple counts of selling and distributing raw milk.[53] In July, 2012, the Ontario Court of Appeal granted the farmer leave to appeal this decision.[54,27]

Some advocates view raw milk consumption as a source of health benefits, including the prevention or treatment of a range of diseases and conditions such as lactose intolerance, allergy, kidney disease, heart disease and cancer.[55]

Prevalence of raw milk consumption

Data on the prevalence of raw milk consumption in the Ontario population is not routinely collected. To estimate the prevalence of raw milk consumption in Ontario, PHO epidemiologists used control data collected for a recent PHO study. From January through August, 2011, the point prevalence of raw milk consumption (defined as self-reported consumption of raw milk in the three days before the survey was conducted) in Ontario was estimated at 1.84 per cent (95 per cent confidence interval 0.75-3.74).[56] In a recent survey of American adults aged 18 years or more, 2.4 per cent of males and 2.1 per cent of females ($p = 0.57$) reported consuming raw milk in the preceding seven days.[57] However, consumption of raw milk may be more frequent in certain groups. For example, in a recent survey of over 2,000 Canadian dairy farmers, 88.7 per cent reported that they or their families consumed raw milk from their bulk tanks. In the same study, 36.3 per cent of dairy farmers surveyed also indicated that the public should be able to (legally) purchase raw milk.[58] Similarly, a recent Waterloo Region survey found that rural residents were more likely to report consumption of raw milk.[59] In summary, there are very limited data on raw milk consumption prevalence in Ontario, but these study findings suggest that raw milk continues to be consumed by some Ontarians.

Methods

The scientific review presented in this report is based on reviews published in the peer-reviewed and grey literature and is supplemented by a scan of recently published primary peer-reviewed and grey literature, as well as unpublished data from Ontario government/agency sources. To obtain published literature, PHO Library Services staff conducted a general search of multiple electronic databases, and PHO staff performed additional focused searches as required.

General search strategy

Please see Appendix B for the detailed search strategy.

- Databases: BIOSIS Previews, Embase, Ovid MEDLINE
- Keywords (including but not limited to):
    - raw* or unpasteur* or untreat* or pasteur* AND
    - milk or dairy products AND
    - pathogen or outbreak* or disease outbreaks or enteric or foodborne or transmission or "public health"
- Limits: English language, time period varied by database (see rationale below)
- Results: Over 1,700 initial results

General search result titles and abstracts were reviewed by Library Services and other PHO staff; additional inclusion criteria outlined in Table 1 were applied. Full-text articles of abstracts that met inclusion criteria were reviewed and coded by topic. Review articles and relevant single studies identified via the literature review are included in this technical document. Focused hand-searching of Canadian and U.S. public health organization web sites (e.g., British Columbia Centre for Disease Control or U.S. CDC), and the reference lists of key reviews was undertaken.

Table 1 Inclusion criteria applied to the results of the general literature search

Category	Criteria for inclusion
Language	English
Publication date	Articles published in the past five years (i.e., 2008 to July/August 2012) were included. Exceptionally, articles pre-dating this period were included.* *These date limits were applied due to: the large body of historical literature on contamination of raw milk and human illness following raw milk consumption (see Background section); the availability of recently published review articles on these topics; the review's emphasis on science relevant to current public health practice in Ontario; the lack of earlier publication date limits applied to supplementary focused literature searches to answer specific research questions for which there is a smaller body of scientific literature; and time and resource constraints.
Publication type	Peer-reviewed journal articles for which the full text was available to PHO and/or formal grey literature reviews (including critical appraisal) by an academic institution were included. This excluded summaries of media, weblog or listserv reports of cases or outbreaks associated with raw milk consumption, such as ProMED,[60] the Barfblog food safety blog[61]or media reports included in the British Columbia Centre for Disease Control's *Summary table of reported illness and outbreaks in North America associated with raw milk/product consumption, 2000-2012*.[62]
Jurisdiction	The jurisdiction in which the exposure occurred and/or the environmental specimen was collected had a similar dairy farming context as Ontario (i.e., Ontario, elsewhere in Canada, the United States and, where appropriate, Australia, New Zealand and Western Europe).
Exposure	The exposure or environmental specimen described was raw (fluid) milk from cows, goats or sheep (i.e., no other unpasteurized dairy products such as raw milk cheese, yogurt or ice cream).
Effect/ Outcome	The effect/outcome described directly addressed the research question(s) (e.g., microbiological contamination of raw milk with a human pathogen; non-microbiological contamination of raw milk; human illness following consumption of raw milk; allergenicity; vitamin content of raw/pasteurized milk; studies of dairy and pasteurization or phosphatase).

Supplementary focused search strategies

Table 2 describes the keywords used for each supplementary focused search strategy. Please see Appendix C for additional details on focused search strategies for published literature.

Table 2 **Supplementary focused search strategies for published literature**

Question	Keywords (including but not limited to the following)
Is there a difference in rates of chemical contaminants between raw milk and pasteurized milk?	▪ raw milk, pasteurization AND ▪ veterinary drug residue, antibiotics, heavy metals, aflatoxin, pesticides, fungicides, parasiticides, dioxin, furan, polychlorinated biphenyl, polyaromatic hydrocarbon persistent organic pollutant
What chemical contaminants have been found in milk in Ontario and comparable jurisdictions?	▪ raw milk, pasteurization AND ▪ veterinary drug residue, antibiotics, heavy metals, aflatoxin, pesticides, fungicides, parasiticides, dioxin, furan, polychlorinated biphenyl, polyaromatic hydrocarbon, persistent organic pollutant
Is there any evidence that raw milk protects against the development of childhood allergies including atopy, asthma and hay fever?	▪ raw milk or pasteurization or milk sterilization AND ▪ allergy or hypersensitivity or atopy or hay fever
Is there any evidence that pasteurization affects vitamins in milk?	▪ pasteurization or sterilization or food preservation or hot temperature AND ▪ milk or dairy AND ▪ vitamin*

Unpublished data sources

To obtain unpublished data on microbiological contamination of raw and pasteurized milk in Ontario, PHO liaised directly with OMAFRA. To obtain recent unpublished data on reported disease cases and outbreaks in humans following consumption of raw milk in Ontario, a PHO epidemiologist extracted case and raw milk exposure information (Jan. 1, 2005–Sept. 30, 2012) from Ontario's centralized electronic notifiable disease reporting system, the integrated Public Health Information System (iPHIS) (see Limitations section). Using iPHIS, Ontario's 36 public health units (PHUs) report specified reportable diseases, in accordance with the *HPPA*[63,24] and Ontario Regulation 559/91,[64] to provincial public health authorities. Descriptive analyses of trends in the incidence of reportable enteric and zoonotic diseases for which consumption of raw milk or raw milk products[iii] was reported as an exposure (whether or not raw milk was identified as the most likely exposure) were analyzed. Cases that reported consumption of raw milk or raw milk products while travelling outside Ontario were excluded from analyses.

[iii] Raw (unpasteurized) milk or milk products refer to liquid milk and milk products such as cheese from any animal source (e.g., cow, goat, sheep, etc.).

Literature review findings

Contamination of raw milk

IS THERE ANY RECENT EVIDENCE THAT RAW MILK IS CONTAMINATED BY HUMAN PATHOGENS, IN ONTARIO AND SIMILAR NORTH AMERICAN JURISDICTIONS?

Key Findings

- Numerous recent U.S. bulk tank studies have identified the presence of human pathogens in raw milk. Pathogens have included *L. monocytogenes, Salmonella* spp., *C. jejuni, Y.enterocolitica* and *E. coli* O157:H7.
- Several recent Ontario bulk tank studies have identified the presence of multiple human pathogens in raw milk from Ontario cows, goats and sheep.
    - One study detected human pathogens (i.e., *L. monocytogenes, Campylobacter* spp. and verotoxigenic *E. coli*) in even the highest-quality samples of raw cow's milk.
    - Another study found *C. burnetii* in 62 per cent of raw cow's milk samples and 24% of raw goat's milk samples.
    - In a new study, *L. monocytogenes* was identified in 4.9 per cent of raw sheep's milk samples.

SUMMARY OF THE LITERATURE

Bulk tank raw milk pathogen prevalence studies in jurisdictions similar to Ontario

- A recent review of U.S. prevalence data for human pathogens isolated from bulk tank and milk filters from at least 20 states from 2000 through 2009 revealed the following:[65]
    - *L. monocytogenes* – five studies with prevalence ranging from 2.8 to seven per cent.
    - *Salmonella* spp. – eight studies with prevalence ranging from zero to 11 per cent.
    - *C. jejuni*– two studies – two per cent and 9.2 per cent.
    - *Y. enterocolitica* – two studies – 1.2 per cent and 6.1 per cent.
    - *E. coli* O157:H7 – four studies ranging from zero to 0.75 per cent.
    - Shiga toxin-producing *E. coli* – four studies ranging from 2.4 to 3.96 per cent.
- In a 2007-2008 U.S. study, *C. burnetii* was detected in nine of 21 (43 per cent) samples tested by PCR from legal, commercially available raw milk sources. Isolates were obtained from two of six PCR-positive samples via mouse inoculation.[66]
- Single Italian vending machine raw milk sample pathogen prevalence study:[67]
    - *L. monocytogenes* (1.01 per cent), *Salmonella* spp. (1.01 per cent), *Campylobacter* spp. (2.02 per cent), and verotoxigenic *E. coli* (1.01 per cent). This study used a modified manual testing method, not the official ISO culture method.

Bulk tank raw milk pathogen prevalence studies in Ontario

- In a 2010-2011 Ontario (OMAFRA) bulk tank study, the following pathogen prevalence estimates were observed, in respect of pathogens isolated from low-, medium- and high-quality raw cow's milk (based on relative individual bacterial counts and SCCs for bulk tank samples in the study), respectively: *L. monocytogenes* (5.4, 5.6, 0.8 per cent), *Salmonella* spp. (0.9, zero, zero per cent), *Campylobacter* spp., (3.1, 1.8, 1.3 per cent), and verotoxigenic *E. coli* (zero, zero, 0.1 per cent).[68]
    - The key finding of this study was that although a gradient was observed between raw milk quality indicators and pathogen prevalence, disease-causing micro-organisms were still observed in the highest-quality raw milk samples. In other words, raw milk containing lower individual bacteria counts, aerobic colony counts and SCC had lower pathogen prevalence than raw milk with higher levels of these quality indicators, but some raw milk samples - regardless of quality indicators – still contained multiple human pathogens.
    - This study was conducted to provide information on the quality of milk needed for the manufacture of raw milk cheese, not raw milk for consumption. The study was not conducted for the purpose of assessing the safety of raw milk for consumption, and as such its results should not be used to assess the safety of raw milk for consumption.
    - These pathogens were also detected in the previous major Ontario on-farm bulk tank study. Analysis of over 1,700 raw milk samples in this 1995-1996 study found the following raw milk pathogen prevalence estimates: *L. monocytogenes* (2.73 per cent), *Salmonella* spp. (0.17 per cent), *Campylobacter* spp. (0.47 per cent), and verotoxigenic *E. coli* (0.87 per cent).[69]
- In a 2008/2009 Ontario study of *C. burnetii*, the causal agent of Q Fever, the pathogen was found in 749/1201 (62 per cent) raw cow milk bulk tank samples and in 57/237 (24 per cent) raw goat milk bulk tank samples. [70]
- In a 2003-2004 study of bulk tank goat milk in Ontario, the prevalence of the following pathogens was observed: *L. monocytogenes* (1.3 per cent), *Salmonella* spp. (0.1 per cent), *Campylobacter* spp. (0.3 per cent), verotoxigenic *E. coli* (zero per cent), and *Y. enterocolitica* (0.6 per cent).[71]
- In a 2011 study of raw sheep milk in Ontario, *L. monocytogenes* was identified in 4.9 per cent of samples, *E. coli* O157:H7 (zero), *Salmonella* spp. (zero), *Campylobacter* spp. (zero), and *C. burnetii* (three per cent). For *L. monocytogenes*, this pertained to 3/44 (6.8 per cent) of farms, and for *C. burnetii* this pertained to 2/39 (5.1 per cent) of farms.[72]

Post-pasteurization milk pathogen prevalence studies in Ontario

- An OMAFRA study that examined the prevalence of selected pathogens in pasteurized fluid milk in Ontario from 2002-2004 found the following: [73]
    - *L. monocytogenes* was not isolated in any fresh pasteurized milk samples, but it was found in two samples at their Best Before dates (or in 0.11 per cent of all samples). The observed prevalence was higher than in a U.S. study of pasteurized milk; the authors suggested methodological differences or shorter retail life of pasteurized milk in the United States as potential reasons for the different results.
    - No *Y. enterocolitica* was isolated from any pasteurized milk sample.

- In the 2.4 per cent of pasteurized milk samples from which *B. cereus* was isolated, pathogen levels did not exceed 300 cfu/mL. The authors concluded that with proper refrigeration this did not present a microbiological safety issue, as per the scientific literature.
- Routine monitoring by OMAFRA of Ontario's fluid milk products (including pasteurized milk) is summarized in Appendix A.

Reviews of *Mycobacterium avium subspecies paratuberculosis* (Map)*prevalence in raw cow's milk

- One systematic review identified three studies with Map prevalence in raw cow's milk by culture of 1.6 per cent, 0.3 per cent and 34.6 per cent. Other studies identified Map via PCR, and one study isolated Map from raw milk from goats with clinical signs of Johne's Disease.[74]
- Another recent review identified three studies of the prevalence of Map in raw cow's milk, in the United States (12 per cent), Denmark (45 per cent) and Canada (34 per cent).[75]

* Map, the causal agent for Johne's disease in ruminants (e.g., cows), has been associated with inflammatory bowel disease (IBD) or Crohn's disease in humans in epidemiologic studies and in clinical research, but Map's possible causal role in human IBD remains uncertain.[76]

IS THERE ANY RECENT EVIDENCE THAT MILK CONTAINS CHEMICAL CONTAMINANTS, IN JURISDICTIONS SIMILAR TO ONTARIO?

WHAT CHEMICAL CONTAMINANTS HAVE BEEN FOUND IN MILK IN ONTARIO AND COMPARABLE JURISDICTIONS?

Key Findings

- Ontario has an active surveillance and enforcement program for antibiotic residues in pre-processed milk from licensed dairy farms. The most recent Ontario surveys demonstrated few environmental contaminant residual levels above established limits.
- Raw milk from non-registered vendors is not monitored for environmental and other contaminants so similar survey data is not available for raw milk from non-registered vendors.
- The literature suggests that pasteurization does not alter the presence of chemical contaminants in milk.

SUMMARY OF THE LITERATURE

Chemical contaminants in raw milk

- The most recent CFIA NCRMP monitoring report from 2006-2007[77] indicated 100-per-cent compliance with mycotoxin and pesticide residue limits. Parasiticides had 99.84-per-cent compliance (three tests were above the MRL), and toxic metals had 99.87-per-cent compliance.
- The most recent surveys conducted by OMAFRA in 2007-2008[78,79,80] demonstrated few residual levels above established MRLs.
- There is some literature documenting the presence of environmental contaminants in raw and pasteurized milk in other countries.[81,82,83,84,85,86] The presence of contaminants such as dioxins, furans and PCBs has been associated with geographic proximity to emitting industries.[87,88,89,90,91]

Pasteurization and chemical contamination

- There is little peer-reviewed literature on the effects of milk processing, including pasteurization, on the presence or absence of chemical contaminants in milk.
- The presence of aflatoxins in milk does not appear to be altered by pasteurization.[92,93]
- The presence of pesticide residues in milk does not appear to be altered by pasteurization.[94,95]
- One small study has demonstrated a statistically significant elevation in PAH in pasteurized milk compared to raw milk.[96]
- Activity levels of certain residual antibiotics appear to be slightly decreased by pasteurization (due to heat instability).[97,98,99,100]

Human illness following raw milk consumption

IS THERE ANY RECENT EVIDENCE LINKING CONSUMPTION OF RAW MILK OR RAW MILK PRODUCTS TO HUMAN ILLNESS, IN ONTARIO AND SIMILAR JURISDICTIONS?

Key Findings

- The recent scientific literature has demonstrated laboratory evidence of indistinguishable Pulsed field gel electrophoresis (PFGE) patterns from human and raw milk specimens from product consumed before illness onset, providing evidence of a causal relationship between raw milk consumption and human illness.
    - Recent epidemiological studies have also demonstrated statistically significant associations between consumption of raw milk and subsequent infectious disease occurrence.
    - The weight of evidence linking raw milk consumption to human illness is strongest for *E. coli*, *Campylobacter* spp. and *Salmonella* spp.
- Public health surveillance data in the United States, Australia and Ontario have linked consumption of raw milk or raw milk products before human illness onset. Despite significant limitations (e.g., under-reporting; see Limitations for further details), previously unpublished surveillance data from Ontario described:
    - Consumption of raw milk or raw milk products were reported as exposures for 256 confirmed cases of reportable, communicable enteric and zoonotic diseases in Ontario (Jan. 1, 2005– Sept. 30, 2012).
    - Campylobacteriosis was the most commonly reported disease, accounting for 69 per cent of cases, followed by cryptosporidiosis at 11 per cent, salmonellosis at eight per cent and verotoxin producing *E. coli* at five per cent.
    - More than half (52 per cent) of the reported cases occurred in infants and children up to 14 years of age.
    - Five of Ontario's 36 PHUs reported 63 per cent of all reported cases with a history of raw milk or raw milk product (e.g., raw milk cheese) consumption prior to illness onset, in Ontario from 2005 through 2012.

SUMMARY OF THE LITERATURE

Systematic review

- A 2008 systematic review of primary studies/reports of human illness associated with the consumption of raw milk products by Massey University in New Zealand found that there was moderate evidence to support a causal link between consumption of raw milk products and four human pathogens: *Campylobacter* spp., *E. coli* spp., *L.monocytogenes* and *Salmonella* spp; and weak evidence to support a link with *Rubella*.[101] To be included in this review, a study had to include both exposed and non-exposed individuals (i.e., cohort, case control and cross-sectional studies, as well as outbreak investigations with information on the total number of exposed individuals).

Microbiological evidence of causality from single outbreak investigations

- A number of enteric outbreak investigations have been published that have established laboratory evidence of links between raw milk consumption and human illness. In these outbreaks, laboratory testing demonstrated indistinguishable PFGE patterns in both human case isolates and samples of raw milk consumed by cases. The most commonly identified pathogens were *Salmonella* spp.,[102,103]*E. coli*[104,105]and *Campylobacter* spp.[106]

- In an outbreak of 10 *Salmonella* Newport cases in Utah in 2010, all cases reported recent consumption of raw milk purchased from two stores supplied by the same dairy. Isolates from all 10 cases were indistinguishable by PFGE and cultures from frozen, raw milk samples from batches of milk sold during the outbreak period also yielded *S.* Newport strains that were indistinguishable by PFGE from the cases linked to the outbreak.[103]

- An outbreak of *Salmonella* Typhimurium was reported among a group of children and adults who participated in dairy farm group tours in 1998.[102] Of 191 visitors to the farm, there were 12 confirmed cases and 35 probable cases. *S.* Typhimurium isolates from human cases, the bulk milk tank, and milk and feces from a cow in the milking herd were genetically identical by PFGE assay. In addition, a cohort study composed of the 1998 tour groups demonstrated that illness (with or without laboratory confirmation) was associated with drinking raw milk from the bulk milk tank (RR=2.74, 95% CI 1.50 to 5.01, p=0.006).

Evidence of association from single epidemiological studies

- Epidemiological evidence, in the absence of a direct microbiological match by PFGE between ill persons and a suspected product, has provided additional statistical and temporal evidence to support a causal relationship between raw milk consumption and illness in humans.[107,106,108]

- In a review of reported outbreaks in the United States between 2000 and 2008, Oliver et al.[65] identified 12 outbreaks associated with raw milk consumption for the following pathogens: *Campylobacter* spp., *E. coli*, *Salmonella* spp. and *L.monocytogenes,* resulting in a total of 435 cases, 58 hospitalizations (includng four cases of hemolytic uremic syndrome (HUS)) and five stillbirths. Although epidemiological evidence in all reviewed studies implicated raw milk as the mostly likely exposure, there were varying levels of microbiological evidence to support a causal association. For six outbreaks, the organism associated with outbreak cases was also isolated from the implicated product, and in two outbreaks the strains isolated from outbreak isolates and the implicated product were indistinguishable by PFGE.

- Adding to laboratory and epidemiological evidence, a dose-response relationship between the frequency or volume of raw milk consumption was investigated in two separate outbreaks.
    - Denny et al.[104] conducted a retrospective cohort study as part of the outbreak investigation and collected information for 102 of 140 exposed individuals regarding raw milk consumption habits. Comparing average daily milk consumption as a dichotomous variable (<1 cup vs. >1 cup: RR= 3.4, 95%CI 0.5 to 25.7; p=0.3, ≤2 cups vs. ≥2 cups: RR=3.8, 95%CI 1.2 to 12.4; p<0.05 and < 3 cups vs. ≥ 3 cups: RR=5.7, 95%CI 1.8 to 18; p<0.05) and a discrete, non-overlapping variable (1 to 1.9 cups, 2 to 2.9 cups, and > 3 cups per day vs. consumption of 0 to 0.9 cups; dose response trend p=0.008), illness was associated with increasing amount of milk consumed. While all confidence intervals were wide reflecting the small sample size, all risk ratios for consumption of two or more cups of raw milk per day achieved statistical significance.
    - Guh et al.[105] also assessed dose-response relation between illness and frequency of milk consumption using a household case-control study. In this study, all 12 confirmed and probable cases were compared with 21 well household members without diarrheal illness during the one week prior to illness onset. Results from the trend analysis demonstrated more frequent raw milk consumption among case patients compared with well household members (p=0.01).
- Raw milk consumption has also been reported in the literature as a risk factor for pathogens such as *Toxoplasma gondii* infection,[109] brucellosis[110] and tick-borne encephalitis.[111] However, due to the limited number of published studies on these topics, it is not possible to evaluate if there is a link between raw milk consumption and *Toxoplasma gondii* infection or tick-borne encephalitis.

Reviews of public health surveillance data from the United States and Australia

- Foodborne illness surveillance data from other jurisdictions has provided evidence of an association between raw milk consumption and human illness. However, since routine public health follow-up of reportable sporadic disease cases often does not include testing of raw milk, source attribution is usually not possible. Both the United States and Australia have published reports examining raw milk and human illness using surveillance data.[112,113,114,115]
- Most recently, Langer et al.[112] reviewed all dairy associated outbreaks reported to the U.S. CDC from 1993 to 2006:
    - 30 states reported 122 foodborne disease outbreaks caused by contaminated dairy products. Pasteurization status was known for 121 of the 122 outbreaks, and most outbreaks (60 per cent, 73 outbreaks) involved unpasteurized dairy products resulting in 1,571 cases, 202 hospitalizations and two deaths.
    - Approximately 90 per cent of the outbreaks involving raw milk products were caused by *Campylobacter*, *Salmonella* and *E. coli*. The remaining outbreaks identified were caused by *Rubella* (four per cent), *L. monocytogenes* (four per cent) and *Shigella* spp. (three per cent).
    - The majority of outbreaks (55 or 75 per cent) occurred in states where the sale of unpasteurized dairy products was legal. In states where it was legal to sell unpasteurized dairy products, the rate of outbreaks caused by raw milk was twice as high as in states where it was

illegal to sell unpasteurized dairy products [incidence density ratio (IDR) = 2.2, 95% CI 1.14 to 4.25].

- The rate of outbreak-associated illness caused by raw milk was 15-per-cent higher in states where it was legal to sell unpasteurized dairy products, but this result was not statistically significant (IDR = 1.15, 95% CI 0.24 to 5.54).

- A review of Australia's OzFoodNet surveillance system also found some evidence of an association between raw milk consumption and human illness.[115] In this review, illnesses associated with seven outbreaks since 2001 were associated with dairy products obtained directly from farms or as commercially available products in the community. In four of these outbreaks, unpasteurized milk was the suspected or definite cause of illness based on testing of foods or epidemiological studies.

Summary of recent Ontario public health surveillance data

Cases of reportable diseases with exposure to raw milk or raw milk products[iv]

- Data from iPHIS have limitations, including a likely under-reporting of exposure (e.g., not recalling or disclosing the consumption of raw milk before becoming ill) and/or of any subsequent illness (e.g., mild enteric illness for which no medical attention is sought/no testing is performed) (see Limitations). Despite these limitations, it was possible to describe previously unpublished disease incidence and exposure data to obtain conservative estimates of the burden of reportable infectious disease cases in Ontario that occur after consumption of raw milk.

- Consumption of raw milk or raw milk products were reported as exposures for 256 confirmed cases of enteric and zoonotic diseases in Ontario from Jan. 1, 2005 through Sept. 30, 2012.

- Campylobacteriosis was the most commonly reported disease, accounting for 69 per cent of cases, followed by cryptosporidiosis at 11 per cent, salmonellosis at eight per cent and verotoxin producing *E. coli* at five per cent (Table 3).

- Just over half (52 per cent) of cases were aged one month to 14 years, and there were slightly more males (57 per cent) than females (Table 4).

- Twenty-five of the 36 PHUs[v] in Ontario reported cases with exposures pertaining to the consumption of raw milk or raw milk products. Five PHUs, representing approximately 9.4 per cent of the Ontario population, [116] reported the highest number of cases and accounted for more than half (63 per cent) of all reported cases who consumed of raw milk or raw milk products in Ontario from 2005 to 2012. In one of these PHUs, 78 per cent (21/27) of cases were related to an outbreak linked to the consumption of raw milk cheese.

[iv] Disease acquisition cannot be definitively attributed to exposures presented within this section but are assumed to be a possible source of acquisition

[v] Public health unit (PHU) refers to diagnosing PHU, which is defined as the PHU where the case lives most of the time. The diagnosing PHU does not necessarily reflect the PHU of exposure, although cases reported as travel-associated were not included.

Table 3. Number of cases who reported consumption of raw milk or raw milk products by disease, Ontario (Jan. 1, 2005, to Sept. 30, 2012)

Disease*	Number of Cases	% Total[b]
Campylobacteriosis	176	69%
Cryptosporidiosis	29	11%
Salmonellosis	21	8%
Verotoxin producing *E. coli* including HUS	12	5%
Listeriosis	6	2%
Giardiasis	5	2%
Other[a]	7	3%
Total	**256**	**100%**

Source: MOHLTC iPHIS database, extracted by PHO [2012/11/07]

[a]Other includes: brucellosis, Q fever, yersiniosis and shigellosis

[b] Column percentages do not sum to 100 per cent due to rounding

*Disease acquisition cannot be definitively attributed to exposures represented in this table but are assumed to be a possible source of acquisition

Table 4. Age and sex distribution of cases who reported consumption of raw milk or raw milk products, Ontario: Jan. 1, 2005, to Sept. 30, 2012

Age Group (years)	Female	Male	Total	Row % (Age group)
0-4	33	56	89	35%
5-14	16	28	44	17%
15-24	18	25	43	17%
25-44	26	16	42	16%
45-64	9	11	20	8%
65+	6	9	15	6%
Unknown	1	2	3	1%
Total	**109**	**147**	**256**	**100%**
Column % (sex)	**43%**	**57%**	**100%**	**N/A**

Source: MOHLTC iPHIS database, extracted by PHO [2012/11/07]

Hospitalizations and deaths

- No deaths were reported among the 256 cases who reported consumption of raw milk or raw milk products from Jan. 1, 2005, through Sept. 30, 2012; however one case of *E. coli* reported HUS and one case of listeriosis infection had a miscarriage.
- Four per cent of cases (N = 11 cases) reported being hospitalized, including four cases under the age of 15 years.
- Hospitalization for at least 24 hours was reported for 11 cases. These hospitalized cases were laboratory-confirmed for campylobacteriosis, cryptosporidiosis, salmonellosis, listeriosis, Q fever and verotoxin producing *E. coli*. Thirty-six percent of hospitalized cases were less than 15 years of age.

Outbreaks

- For the purposes of this summary, an outbreak is defined as two or more cases that have been linked in iPHIS to a common source of unpasteurized milk or milk product.
- From Jan. 1, 2005, through Sept. 30, 2012, two outbreaks were reported in iPHIS.
  - The first was an *E. coli* outbreak in 2005 composed of three cases linked to raw milk.
  - The second was a campylobacteriosis outbreak associated with the consumption of raw milk cheese (investigated in 2007). Of the 21 cases linked to this outbreak, one case was hospitalized.

Selected possible benefits of raw milk consumption and/or harms of milk pasteurization

IS THERE ANY RECENT EVIDENCE THAT RAW MILK IS PROTECTIVE AGAINST DEVELOPING CHILDHOOD ATOPY, RHINO/CONJUNCTIVITIS AND ASTHMA?

Key Findings

- The literature reviewed suggests a possible association between consumption of raw milk and decreased incidence of childhood atopy, hay fever and asthma.
- This observed possible association may be due to potential confounders (e.g., other factors linked to farm settings) or to bias related to the design of observational studies (e.g., parents of children with asthma may recall raw vs. heat-treated milk consumption differently than parents of children without asthma).
- No mechanisms for a protective effect of raw milk consumption were identified in the literature reviewed.

SUMMARY OF THE LITERATURE

Raw milk and atopy/rhino/conjunctivitis/asthma

- A systematic review and meta-analysis of six studies on the association between raw milk and development of childhood allergies was completed in 2011.[117] Although the review concluded that the consumption of raw milk was associated with a decrease in the odds of having childhood allergies, the review was limited by poor methodological quality of the studies included in the analysis and

failed to isolate raw milk from confounding factors of farm exposure protective against allergy development.

- Many cross-sectional epidemiological studies have shown associations between drinking raw milk and decreased prevalence of hay fever, atopic dermatitis, atopic sensitization, or asthma in children.[118,119,120,121,122,123] However, these studies have had inferential limitations in terms of the temporal sequence of the exposure and health effects, and potential confounding factors.
- For example, the GABRIEL Advanced study was a large, recent multi-centre European cross-sectional study that assessed farm exposures as well as raw milk consumption in relation to the development of asthma, hay fever and atopy.[119]
    - When data for 8,419 school-aged children were stratified by different farm exposures, consumption of raw cow's milk was found to have a protective effect independent of other farm exposures (asthma OR 0.77, CI 0.66-0.90, p<0.001; atopic sensitization OR 0.73, CI 0.64-0.84, p<0.001).
    - The GABRIEL study was not designed to test for a preventive or therapeutic effect of unboiled farm milk (i.e., raw milk) consumption, and it did not assess the direction of possible causal links. Findings may have been influenced by residual confounding (e.g., the study may not have fully controlled for all relevant factors related to living in a farm setting), and/or by recall bias (e.g., parents of asthmatic children may have recalled and reported past consumption of store milk more often, and *vice versa*).
    - Study authors did not infer that farm milk would be effective to prevent asthma, noting that the mechanisms underlying the observed findings are not fully understood or known. Study authors concluded that raw milk consumption cannot be recommended based on current evidence, due to potential pathogens in raw milk.

- Researchers have attempted to identify molecular level pathways to explain the potential protective effect of raw milk. This has included examination of various microbes, whey proteins, cytokines and endotoxins; however, the potential mechanism remains poorly understood.[120,124]

IS THERE ANY RECENT EVIDENCE LINKING MILK PASTEURIZATION TO MILK ALLERGIES?

Key Findings

- The literature reviewed suggests that heat treatment processes such as pasteurization can alter the structure of certain milk proteins.
- The degree to which this may contribute to clinical milk allergies and the mechanism by which heat treatment may affect the allergenicity of milk proteins is not fully understood. In addition, our review identified some inconsistent findings about the direction of the association between heat treatment and allergenicity of milk, as some studies suggest a link between heat treatment and decreased allergenicity of milk.
- Our review did not identify any reported cases of milk allergies attributed to altered milk proteins.

Pasteurization and milk allergies

- Heat treatment processes such as pasteurization of milk can lead to changes in protein, which is hypothesized to alter the allergenic potential of milk proteins.[125] Heat-denatured proteins can present new antigenic sites or epitopes, uncovered by the unfolding process or created by new chemical reactions with other molecules present in the food (e.g., beta-lactoglobulin associating with alpha-lactalbumin in milk).[126] However, structural homology does not reliably predict the effect of processing on allergenicity, and individual food allergens have to be tested.[127] Interactions with other proteins, fat and carbohydrates in the food matrix are complex and poorly understood.[128]
- There is conflicting evidence regarding biomarkers involved in potential allergenicity.[129,130,131,132,133,134] Some studies demonstrated that heat treatment can actually reduce but not eliminate the allergic potential of milk proteins.[135,136] One summary article concluded that the available evidence is not sufficient to establish an intake threshold below which allergic reactions are not triggered.
- Biomarkers associated with increased allergenicity investigated in research articles included in this review are: histamine release, antibody and cytokine production, anaphylaxis, antibody binding, levels of total serum antibodies (i.e., immunoglobulin E, beta-lactoglobulin specific immunoglobulin G1, immunoglobulin G2a, interleukin-4 and interferon-gamma), numbers of mononuclear inflammatory cells and eosinophils, and heat-induced conformational changes to key milk proteins.

IS THERE ANY RECENT EVIDENCE THAT PASTEURIZATION AFFECTS VITAMINS IN MILK?

Key Findings

- A systematic review found some evidence that pasteurization decreased the concentrations of vitamins B12 and E, increased vitamin A and had no statistically significant different on vitamin B6 concentration in milk. However, the authors concluded that the effect of pasteurization on milk's nutritive value was minimal because milk is not considered an important dietary source of these vitamins.

SUMMARY OF THE LITERATURE

- A 2011 systematic review and meta-analysis concluded:[117]
    - Pasteurization appeared to decrease concentrations (in mg/L) of vitamins B12 and E and increase vitamin A. Meta-analysis could not be performed because appropriate information was not provided in the studies. These descriptive results should be interpreted with caution. Milk is not an important source of B12 or E, thus the authors concluded that the effects of pasteurization on the adult daily intake of these vitamins is negligible.
    - Random effects meta-analysis revealed no significant effect of pasteurization on vitamin B6 concentrations (standardized mean difference, 95-per-cent confidence interval) (-2.66, -5.40 to 0.8), and a decrease in concentrations of vitamin B1 (-1.77, -2.57 to -0.96), B2 (-0.41, -0.81 to -0.01), C (-2.13, -3.52 to -0.74) and folate (-11.99, -20.95 to -3.03). (All vitamin concentrations were converted to mg/L).

- The effect of pasteurization on milk's nutritive value was minimal because milk is not considered an important dietary source of these vitamins. However, milk is an important dietary source of vitamin B2, and the impact of heat treatment should be further considered.

- Our review did not identify additional relevant single studies published after the systematic review was conducted.

Portable testing methods to identify raw milk

IS THERE ANY EVIDENCE TO SUPPORT PORTABLE METHODS TO TEST FOR THE PRESENCE OF RAW MILK?

Summary of the literature

As of August, 2012, our review of peer-reviewed literature did not identify any described or evaluated portable tests that could be used to assess the adequacy of milk pasteurization (i.e., to detect the presence of raw milk) in the field without minimal laboratory resources (Appendix D).

Limitations

This scientific review aimed to identify and summarize the recent scientific literature related to raw milk consumption and public health practice in Ontario, but several limitations merit consideration.

Given time and resource constraints, this review did not seek to identify all potentially relevant historical and international evidence on raw milk contamination and human illness linked to raw milk consumption. In the context of a large body of historical and international scientific literature on these topics (see Background for examples of historical scientific literature), our review of scientific literature on raw milk contamination and human illness linked to raw milk consumption was limited to more recent literature (see Methods). Another limitation of our literature review on microbiological and non-microbiological contamination of raw milk was the lack of available data (e.g., pathogen prevalence studies, environmental contaminant monitoring studies) from unlicensed/non-registered dairy producers (farmers) that operate outside the system for monitoring licensed/registered producers, due to the unregulated nature of these activities and the regulators' inability to access these dairy producers.

No publication date or jurisdictional limits were used in supplementary focused literature searches on selected possible benefits of raw milk consumption and/or harms of milk pasteurization and portable testing methods to identify raw milk given the relatively smaller bodies of scientific literature on these topics. Nevertheless, our review may not have captured all relevant evidence on these topics. In addition, due to time and resource constraints, this review did not examine the scientific literature on other possible health benefits of consuming raw milk (e.g., in relation to lactose intolerance, kidney disease, heart disease or cancer); possible health benefits related to milk processing beyond pasteurization; or other possible adverse effects of consuming pasteurized milk (e.g., related to additives such as vitamin D and omega-3 or related to other milk processing activities, such as homogenization). In addition, the literature review on raw milk consumption and development of childhood allergies only sought to identify and review scientific evidence that suggested a possible protective effect of raw milk consumption on allergy development; as per stated objectives, the report did not seek to identify or review evidence to the contrary. A review published in 2013 highlights some of the additional possible harms and benefits associated with raw and heated (i.e., pasteurized/sterilized) milk consumption that were beyond the scope of this report. [137]

The lack of routinely collected data on raw milk consumption in Ontario or Canada is another limitation of this review (see Background). In addition, the limitations of the Ontario iPHIS public health surveillance data presented in this report constrain our ability to quantify the risk of human illness following raw milk consumption. iPHIS is a dynamic disease reporting tool that allows ongoing updates. As such, extracted data represents a snapshot at the time of extraction. iPHIS is a passive surveillance system and, similar to other passive reporting systems, iPHIS is characterized by limitations including underreporting of cases, incomplete reporting of related case details such as clinical outcomes (e.g., hospitalization) and exposures, as well as difficulty in attributing illness to reported sources. iPHIS was implemented in phases starting in April, 2005, and data related to exposures and clinical outcomes are less reliable for years prior to the release of user guides starting in 2007. As many pathogens that have been found in raw milk cause enteric illness, underreporting of enteric illness in iPHIS and in general is a limitation of particular note. Underreporting of enteric illnesses may occur for many reasons. For example, symptoms may be mild or individuals may not seek medical treatment[138] and thus are not eligible for laboratory testing. In a report by Majowicz *et al*,[139] it is estimated that one in every 313 cases of enteric illness in the community is reported to public health.

Estimating the risk of developing disease (and severe disease) following consumption of raw milk would require analysis of multiple factors that we did not set out to analyze in this report. As with foodborne illness in general,[140,139] these factors could relate to the host (e.g., the age and underlying health status of raw milk consumers in Ontario, the amount of raw milk consumed), the contaminating agent (e.g., the particular microbiological contaminant(s), their pathogenicity, the infective dose(s)), and the physical and social environment (e.g., prevalence of raw milk contamination with particular human pathogens, as well as factors related to seeking and receiving health care in raw milk consumers who become ill). As noted above, estimating the public health impact of disease risk associated with raw milk consumption in Ontario would also require better data on the prevalence of and context for raw milk consumption in the Ontario population overall, and in subgroups within it.

In summary, this scientific review had limitations related to its scope, as well as the type and quality of available exposure data (e.g., raw milk consumption data) and possible health effects data. These limitations precluded a quantitative, comparative risk analysis of all the possible health benefits and harms of raw milk versus pasteurized milk consumption in the Ontario population, the probability of these benefits and harms occurring and their public health impact.

Conclusions

In spite of the limitations outlined above, this scientific review identified multiple reviews and single studies relevant to the Ontario context that demonstrate raw milk's potential as a health hazard, primarily via microbiological contamination. We also identified evidence from a systematic review, laboratory and epidemiological studies and Ontario reportable disease exposure data affirming the association between consumption of raw milk and human illness following infection with pathogens including but not limited to *E. coli*, *Campylobacter* spp. And *Salmonella* spp.. This review also identified some observational studies that suggest a possible association between consumption of raw milk and decreased incidence of childhood atopy, hay fever and asthma. Of note, residual confounding and bias related to observational study design may have influenced these findings, and the literature reviewed did not identify mechanisms to explain this possible protective effect of raw milk consumption. This review did not identify evidence of an association between altered milk proteins and milk allergies. Finally, iterative searching in multiple databases did not identify any evidence for the effectiveness of portable methods for detecting raw milk.

Finally, this scientific review also suggested that opportunities may exist to strengthen surveillance and research on knowledge, attitudes and behaviours related to raw milk consumption in the Ontario and Canadian populations. For example, future food consumption and/or behavioural risk factor surveys could include questions on raw milk product consumption.

Appendices

APPENDIX A: OMAFRA'S DAIRY FOOD SAFETY PROGRAM[141,20]

OMAFRA shares responsibility for the province's production, transportation, processing, packaging and distribution of safe, high-quality cow and goat milk and milk products with federal and municipal governments and industry. The government's role is to provide oversight to ensure that producers, transporters and manufacturers are operating under conditions that meet all relevant provincial regulatory requirements of the *Milk Act*. Some of the functions that achieve this are:

Ontario's Raw Milk Quality Programs apply to the production of raw milk on dairy farms and its transportation to dairy plants for processing. The programs are based on a comprehensive legislative framework in the *Milk Act* (Ontario) and include inspection of farm premises and tank trucks, certification and inspection of bulk tank milk graders on milk collection procedures, oversight of milk collection and transportation to dairy plants and laboratory testing of raw milk samples for composition (fat, protein, lactose and other solids), bacteria content, somatic cell count levels, the presence of chemical residues and abnormalities.

Ontario's Dairy Plant Licensing and Inspection program includes the licensing of all Ontario dairy plants and inspection oversight by either CFIA or OMAFRA.

Federally registered plants are inspected by CFIA and non-federally registered plants are inspected by OMAFRA. Each licensed facility that is inspected by OMAFRA receives the equivalent of one comprehensive in-depth inspection annually and as many follow-ups as necessary to ensure compliance with all applicable regulatory requirements.

OMAFRA conducts routine targeted finished-product sampling and testing along with environmental monitoring programs to check that milk products produced in provincially licensed dairy plants are being made in a safe environment and meet all the applicable standards.

Retail outlets attached to a dairy plant fall under municipal jurisdiction and are inspected by officials from the local public health unit.

Milk from species other than cows or goats

OMAFRA does not license or inspect dairy production, transportation or processing operations that handle milk only from species other than cow and goat (i.e., other species). Milk from species other than cow and goat is not regulated under the *Milk Act*.

If finished milk products from other species are distributed out of the province or are used in federal plants as dairy inputs, the CFIA will register and inspect the plant.

The local public health unit inspects facilities that process milk only from species other than cow and goat and are not federally registered. In general, PHUs are responsible for ensuring that these operations are in compliance with Food Premise Regulation 562.

Fluid Milk Distribution

OMAFRA licenses and inspects distributors of fluid milk products to ensure milk products are stored and transported under appropriate conditions.

APPENDIX B: GENERAL SEARCH STRATEGY

#	Searches	Results
1	pasteurization/	1,165
2	(pasturi* or pasteur* or unpasteur* or nonpasteur* or raw or untreat*).mp.	400,103
3	1 or 2	400,103
4	exp dairy products/or milk/or cheese/or yogurt/or yoghurt/or ice cream/or butter/or cream/	108,891
5	(dairy or milk or cream or butter? or "ice cream" or yog?urt or cheese?).mp.	293,160
6	4 or 5	295,160
7	disease outbreaks/	110,468
8	(brucell$ or campylobacter$ or diptheri$ or Q-fever or "coxiellaburnetti" or cryptosporidi$).mp. orexpescherichia coli/ or "E coli".mp. or "haemolytic uremic syndrome".mp. or "hemolytic uremic syndrome".mp. or HUS.mp. or HAV.mp. or hepatitis a/ or "tickborne encephalitis".mp. or listeri$.mp. or poliovirus.mp. or poliomyelitis.mp. or salmonella.mp. or salmonellosis.mp. or paratyph$.mp. or shigell$.mp. or MRSA.mp. or staphylococc$.mp. or "scarlet fever".mp. or toxoplasm$.mp. oryersini$.ti.	1,043,255
9	(brucell$ or campylobacter$ or diptheri$ or Q-fever or "coxiellaburnetti" or cryptosporidi$).mp. orexpescherichia coli/ or "E coli".mp. or "haemolytic uremic syndrome".mp. or "hemolytic uremic syndrome".mp. or HUS.mp. or HAV.mp. or hepatitis a/ or "tickborne encephalitis".mp. or listeri$.mp. or poliovirus.mp. or poliomyelitis.mp. or salmonella.mp. or salmonellosis.mp. or paratyph$.mp. or shigell$.mp. or MRSA.mp. or staphylococc$.mp. or "scarlet fever".mp. or toxoplasm$.mp. oryersini.ab. /freq=2	1,032,159
10	(outbreak* or enteric or foodborne or "food poisoning" or pathogen or transmi* or "public health").mp.	2,293,122
11	7 or 8 or 9 or 10	3,167,539
12	3 and 6 and 11	5,983
13	limit 12 to (english or french)	5,502
14	limit 13 to last 7 years	3,173
15	remove duplicates from 14	1,763

APPENDIX C: FOCUSED SEARCH STRATEGIES

Question: Is there a difference in rates of chemical contaminants between raw milk and pasteurized milk?

- Databases: OVID (MEDLINE, Embase, Healthstar, journals), PubMed, Web of Knoweldge
- Keywords (including but not limited to):
    - raw milk, pasteurization AND
    - veterinary drug residue, antibiotics, heavy metals, aflatoxin, pesticides, fungicides, parasiticides, dioxin, furan, polychlorinated biphenyl, polyaromatic hydrocarbon, persistent organic pollutant
- Limits: English language

Question: What chemical contaminants have been found in milk in Ontario and comparable jurisdictions?

- Databases: BIOSIS Previews, Embase, Ovid MEDLINE
- Keywords (including but not limited to):
    - raw milk, pasteurization AND
    - veterinary drug residue, antibiotics, heavy metals, aflatoxin, pesticides, fungicides, parasiticides, dioxin, furan, polychlorinated biphenyl, polyaromatic hydrocarbon, persistent organic pollutant
- Limits: English language, 1990-present

Question: Is there any evidence that raw milk protects against the development of childhood allergies including atopy, asthma and hay fever?

- Databases: Ovid (MEDLINE, Embase, Healthstar), PubMed
- Keywords (including but not limited to):
    - raw milk or pasteurization or milk sterilization AND
    - allergy or hypersensitivity or atopy or hay fever
- Limits: English language

Question: Is there any evidence that pasteurization affects vitamins in milk?

- Databases: BIOSIS Previews, Embase, Ovid MEDLINE, CINAHL, EBSCOhost
- Keywords (including but not limited to):
    - pasteurization or sterilization or food preservation or hot temperature AND
    - milk or dairy AND
    - vitamin*
- Limits: English language, 2009 to present (to capture any relevant peer-reviewed literature published after the recent systematic review was conducted)

Question: Novel portable testing methods for detection of raw milk

- Databases: PubMed, Web of Science, Embase, CINAHL, PsychInfo
- Keywords (including but not limited to):
    - "phosphatase dairy" or "phosphatase dairy rapid" or "phosphatase dairy direct, or "field pasteurization test" or "fast test pasteurization" or "phosphatase milk direct" or "rapid pasteurization test" or "phosphatase dairy point of care" or "phosphatase milk point of care"
- Limits: None

APPENDIX D: SEARCH RESULTS FOR PORTABLE TESTING METHODS TO IDENTIFY RAW MILK

Search terms	Phosphatase dairy rapid	Phosphatase dairy direct	Phosphatase dairy point of care	Phosphatase milk point of care
Applied Science Full Text	0	0	0	0
CINAHL Plus	0	0	0	0
Embase.com	27 (4)	18 (0)	2 (0)	6
General Science Full Text	0	0	0	0
PsycInfo	0	0	0	0
PubMed	8 (3)	6 (0)	0	0
Web of Science	17 (6)	11 (0)	0	0

(#) are those that are applicable to testing of dairy for pasteurization or phosphatase.

Search terms	Field pasteurization test	Fast test pasteurization	Phosphatase milk direct	Rapid pasteurization test	Phosphatase dairy
Applied Science Full Text	0	0	0	0	0
CINAHL Plus	0	0	2 (0)	0	2 (0)
embase.com	5 (0)	1 (0)	26 (0)	5 (1)	798 (48)
General Science Full Text	0	0	0	0	0
PsycInfo	1 (0)	0	0	0	1
PubMed	5 (1)	3 (0)	23 (0)	8 (2)	218 (9)
Web of Science	19 (2)	3 (0)	32 (1)	11 (3)	323 (19)

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