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Farm to consumption risk assessment for *Staphylococcus aureus* and staphylococcal enterotoxins in fluid milk in China

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A B S T R A C T

The objective of this study was to conduct a risk assessment to determine the food poisoning risk from the consumption of milk in China that might be contaminated by *Staphylococcus aureus*. Data related to prevalence and concentration of *S. aureus* in fluid raw milk in China were collected from the literature and used to calculate the initial contamination levels. Two main consumption routes were considered and the results of the Monte Carlo simulation model indicated that the storage temperature in the processing plant and heat processing of milk in the home were the primary factors affecting the *S. aureus* concentration at the processing plant and the home before consumption, respectively. Other important factors were distribution of log (D)-value's for *S. aureus*, storage temperature and time on farm, temperature of the thermal treatment of milk, and treatment time at the dairy processing plant. To minimize the risk of milk-borne staphylococcal intoxication in China, the key step appears to be the control of storage conditions during the period after heat treatment and before consumption. The risk assessment model developed in present study provides valuable information for Chinese government and dairy processors to improve milk safety. It also could provide valuable recommendations for Chinese consumer education on safe handling of milk products.

1. Introduction

Milk and dairy products are important food of many diets around the world. Milk can provide nutrients essential for human health, especially for the very young and the very old (Kandpal, Srivastava, & Negi, 2012). Research has showed that milk products can help to reduce the risk of several diseases, including osteoporosis and hypertension (Huth, Dirienzo, & Miller, 2006). Milk and dairy products provided more than 70% of calcium in the in US diet (Huth et al., 2006). Milk has also become an important component of a balanced diet in China (Liu & Wang, 2013). Milk demand and supply has shown growth in China in past 2 decades, and the annual per capita milk consumption increased from 9.23 kg in 1992 to 24.87 kg in 2007 (Qian, Guo, Guo, & Wu, 2011).

Milk also serves as a suitable medium for the growth of numerous microorganisms, some of which (e.g., pathogenic *Escherichia coli*, *Listeria monocytogenes*, enterotoxigenic *Staphylococcus aureus*) can cause human illness and disease. While pasteurization has been extensively used as an effective technology to control foodborne pathogens, pasteurization may not destroy high levels of pathogens in milk, improper pasteurization may not destroy foodborne pathogens, and pathogens present in post-pasteurization processing environments may recontaminate of dairy products (Oliver, Jayarao, & Almeida, 2005). Foodborne outbreaks associated with the consumption of milk and dairy products occur each year and an estimated 6,561,951 annual foodborne illnesses are attributed to dairy products caused by a variety of pathogens in the United States, resulting in an estimated 7464 hospitalizations and 121 deaths (Painter et al., 2013).

S. aureus is one of the pathogens of particular concern in milk safety. A survey of contamination levels of *S. aureus* in Californian raw milk was conducted, and the results showed that among 51,963

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milk samples, the prevalence of *S. aureus* was 25.3% (Heidinger, Winter, & Cullor, 2009). A survey for *S. aureus* in raw milk was conducted in Heilongjiang Province, China and *S. aureus* was detected in 83.5% of 400 raw milk samples and the probability of $\geq 10^5$ CFU/mL of *S. aureus* was 25.6% (Yu et al., 2010).

Quantitative microbiological risk assessment (QMRA) can be used to evaluate microbiological risks and factors for control of foodborne hazards. It can help in the development of more effective Hazard Analysis and Critical Control Point (HACCP) plans and Good Manufacturing Practice (GMP) procedures to protect consumers from pathogens and toxins (Jaykus, 1996). Several risk assessments for the presence of *S. aureus* and *Staphylococcus* enterotoxins (SEs) in milk and dairy products have been conducted (Barker & Gomez-Tome, 2013; Gonzalez, Hartnack, Berger, Doherr, & Breidenbach, 2011; Makita, Desissa, Teklu, Zewde, & Grace, 2012). A complete microbiological risk assessment defined by Codex Alimentarius Commission (CAC) contains four components: hazard identification, hazard characterization (or dose–response), exposure assessment and risk characterization. Given the lack of a dose–response model for *S. aureus*, exposure assessment becomes the best means to estimate exposure to *S. aureus* and *Staphylococcus* enterotoxins in milk in China.

The objective of this study was to develop a quantitative microbiological risk assessment model to evaluate the exposure risk of *S. aureus* and SEs in milk from farm to consumption in China. The contamination levels of milk collected from different areas, the temperature and time during the transportation and storage were considered and described using a stochastic approach for dairy processing and direct to consumer routes respectively. Finally, the toxin production at certain contamination levels of *S. aureus* was used to estimate risk of exposure to SEs.

2. Materials and methods

2.1. Hazard characterization

Hazard characterization describes the dose–response relationship for evaluation of the adverse health effects associated with the relevant foodborne pathogen. Dose-response models describe the relationship between a given exposure dose and the likelihood of a specified response in a specified population (FAO/WHO, 2004). A published dose response model for skin infection case caused by *S. aureus* has been reported (Rose & Haas, 1999; Tamrakar, 2012), but no published dose response model describing the relationship between the probability of illness and ingested *S. aureus* Enterotoxin dose has been developed (Bahk et al., 2006; Lindqvist, Sylven, & Vagsholm, 2002; Rho & Schaffner, 2007). Therefore, a dose response relationship between ingested *S. aureus* or SEs was not considered in the present study.

The total annual consumption of milk per person in China was reported to be 32.4 kg/year by the Chinese Ministry of Agriculture, and fraction of milk consumed as fluid milk was 20% (Wang, 2013). The average daily intake of milk products per person was estimated to be 32.4 (kg/year) * 20% *1000 (g/kg)/1.028 (g/ml)/365 (d/year).

2.2. Exposure assessment

The farm to consumption distribution chain for milk in China is illustrated in Fig. 1. The distribution chain is comprised of a series of operations including raw materials, storage, transportation, heat treatment and storage. The unit operations related to the potential growth and reduction of *S. aureus* are indicated in Fig. 1. Table 1 shows the framework of the exposure assessment including values, variable and distribution for *S. aureus* in milk from farm to consumption, the details of which are described below.

The data related to the contamination level of raw milk were derived from the literature (Bai et al., 2014; Fan, 2012; Gao, Liu, Ban, Wen, & Cui, 2010; Han, Xie, Han, & Tang, 2009; Hu et al., 2013; Huang, Deng, Tan, & Liao, 2009; Lei, Chai, Xie, & Shi, 2010; Li, 2010; Li, Yi, Pan, Deng, & Liang, 2012; Lin, Pang, & Fan, 2006; Ling, Yu, Han, Li, & Jia, 2008; Liu, Li, Liang, & Zhen, 2007, 2008, 2009; Luo et al., 2011; Li, 2010; Quan, Hu, Hu, & Su, 2008; Suo, Yu, Ling, & Jia, 2008; Wang et al., 2010; Xu & Cao, 2005; Xu, Yan, & Zhang, 2010; Xue et al., 2012; Yang, Liu, Gong, Huang, & Xin, 2006; Yin, Chao, & Gu, 2006; Zhang, Wang, & Zhang, 2004; Zheng et al., 2006; Zhao & Pang, 2009; Zhang, Yang, & Jin, 2009, 2011a, 2011b), comprising a total of 30 references with monitoring data (Table 2). Those 30 references include 3279 individual samples with 800 samples positive for *S. aureus*. The contamination levels of *S. aureus* in milk were quantified using qualitative data considering detectable and nondetectable levels (Jarvis, 2000). The proportion of raw milk with detectable level of *S. aureus* was estimated using Beta distribution (Bemrah, Sanaa, Cassin, Griffiths, & Cerf, 1998). The contamination level from the presence-absence tests was calculated as per Jarvis (2000).

$$D_m = -(2.303/V)\log(Z/N)$$

where D_m is the true density of microbes in the batch, V is the quantity of material tested, Z is the number of servings testing negative, and N is the total number of serving examined. According to our monitoring information (where $V = 25$ g), the above equation can be changed to $-(\text{Ln}\ (10))/25\ \log(Z/N)$, i.e. $-\text{Ln}(\text{Pn})/25$, where Pn was the proportion of raw milk with nondetectable level of *S. aureus*.

Temperature and time during transportation and storage are important factors affecting bacterial growth in foods that support growth (Fig. 1). Milking on Chinese farms is conducted at room temperature (23 ± 1 °C) and is normally stored in milk storage tank for 3–24 h at 4–7 °C after collection and then transferred to dairy processing plants or retail locations using refrigerated tanker trucks. According to the survey, the most likely transportation time to dairy processing plants was 12 h. If milk is transferred to a processing plant, it will be stored for a maximum 24 h (with a total maximum of 48 h including the storage time at farm) at 4–7 °C before processing. This is consistent with the operation guidelines proposed for Chinese dairy factories. If the raw milk is sent for retail locations for sale, the transportation time is always within 6 h since this kind of retail stores is located not far from the cattle range or farm. The retailers and consumers always do not let the raw milk over night for the purpose of safety consumption. Therefore, it is distributed to retailers and consumers within almost 12 h. Chinese consumers typically boil raw milk prior to consumption. The cooling period after boiling was ignored in this risk assessment since typical practice is to consume milk soon after boiling.

The distribution chain was divided into three stages for the purposes of this risk assessment. Those stages were (1) storage at farm and transportation to retail stores or dairy processing plant; (2) transportation to retail stores after processing in dairy processing plant, display for sale at retail, transportation to home and storage at home; (3) display for sale at retail, transportation to home and storage at home. The time and temperature during storage at farm and transportation to dairy processing plant were described by a pert distribution, Pert (3, 24, 48) and Pert (4, 7, 23), respectively. The temperature for transportation to retail locations is used the same pert distribution (4, 7, 23) while a pert distribution (3, 18, 30) is applied to describe the storage and transportation time. The typical shelf life of most Chinese pasteurized milk products is 3 days, sometimes up to 7 days in winter according to our survey for normal pasteurized milk products. Raw milk is