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Review

Foodborne viruses: Detection, risk assessment, and control options in food processing

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ABSTRACT

In a recent report by risk assessment experts on the identification of food safety priorities using the Delphi technique, foodborne viruses were recognized among the top rated food safety priorities and have become a greater concern to the food industry over the past few years. Food safety experts agreed that control measures for viruses throughout the food chain are required. However, much still needs to be understood with regard to the effectiveness of these controls and how to properly validate their performance, whether it is personal hygiene of food handlers or the effects of processing of at risk foods or the interpretation and action required on positive virus test result. This manuscript provides a description of foodborne viruses and their characteristics, their responses to stress and technologies developed for viral detection and control. In addition, the gaps in knowledge and understanding, and future perspectives on the application of viral detection and control strategies for the food industry, along with suggestions on how the food industry could implement effective control strategies for viruses in foods. The current state of the science on epidemiology, public health burden, risk assessment and management options for viruses in food processing environments will be highlighted in this review.

1. Introduction and background

1.1. Introduction

Foodborne disease is a significant contributor to the global disease burden (Table 1). Outbreaks and illnesses caused by foodborne microbial pathogens place a heavy burden on health, not only through illness but also through the costs associated with measures taken to reduce the impacts on populations. In today's world with its global reach, the potential for the spread of foodborne illness across country and continental barriers is immense. Worldwide, Norovirus (NoV) is the leading agent of acute gastroenteritis (Table 1), causing about 1 in 5

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Table 1
Contribution of viruses to global burden of foodborne disease.[a]

Diseases/ infections	Foodborne illness (millions)	Percentage of total illnesses	Foodborne DALYs (millions)	Percentage of total DALYs
Total foodborne	600	–	33.0	–
Norovirus	120	20%	2.5	7.6%
Hepatitis A virus	14	2%	1.4	4.2%

[a] Global burden of foodborne disease expressed as total number of illnesses and Disability Adjusted Life Years (DALYs). Percentages are calculated based on the Total Foodborne Disease Burden. Data from 2010. Adapted from WHO estimates of the global burden of foodborne diseases: Foodborne Disease Burden Epidemiology Reference Group 2007–2015 (World Health Organization, 2016).

cases in developed countries (CDC, 2016). In countries where rotavirus vaccines are implemented, NoV has surpassed rotaviruses as the most common cause of childhood gastroenteritis requiring medical attention (Payne et al., 2013).

The Centers for Disease Control and Prevention (CDC) conducted detailed analyses of gastroenteritis outbreaks in the US between 2009 and 2012 and 48% or 1008 of the 2098 foodborne illness outbreaks reported were due to NoV (Hall et al., 2014). Restaurants were the most common setting for these outbreaks with the majority of these attributed to infected food handlers (70%). It is interesting to note that of the 324 outbreaks where a food item was identified only 67 outbreaks reported contamination linked to a single category of food (Hall et al., 2014). The most common categories of food linked to outbreaks were leafy greens, fresh fruit and shellfish. However, any food can be implicated in outbreaks. Contaminated raw ingredients or fresh produce can be sourced from very distant locations and used as ingredients in a wide variety of foods, thereby increasing the potential for spread of infection and impact of illness across the food industry. In 2012, frozen berries – specifically strawberries – were implicated in large-scale outbreaks of NoV and Hepatitis A virus (HAV). During a 2-month span in 2012, approximately 11,000 people in Germany were affected by NoV gastroenteritis. Epidemiological investigations found that frozen strawberries imported from China were the vehicle of contamination (Mäde et al., 2013) while HAV in frozen mixed berries from various countries (Canada, Bulgaria, Serbia and Poland) was linked to an increase in cases in Northern Italy (Rizzo et al., 2013).

Foodborne illness also carries a high economic burden and it is estimated to cost the US economy between $55.5 and $93.2 billion per year (Scharff, 2015). In the Western World, comprehensive analyses are available for the health impacts of foodborne viral disease such as the study by Hoffmann et al. (2012) based on 2011 data in the US. In this study, five pathogens, nontyphoidal *Salmonella enterica*, *Campylobacter* spp., *Listeria monocytogenes*, *Toxoplasma gondii*, and NoV, accounted for approximately 90% of the total quality-adjusted life years (QALYs) with NoV alone contributing 5000 lost QALYs. This translates into a cost of approximately $2 billion per year due to NoV (Hoffmann et al., 2012), while studies in the Netherlands reported the costs of NoV and HAV illnesses in 2012 to be around €106 million and €900,000, respectively (Mangen et al., 2013 and 2015).

Consequently, foodborne viruses are recognized among the top food safety priorities in a recent report by risk assessment experts who applied the Delphi technique (Rowe and Bolger, 2016). Thus, over the past few years foodborne viruses have become a greater concern to both the food industry and regulatory bodies. It is only recently that infections caused by foodborne viruses have started to be routinely monitored in surveillance systems and this is only performed in some industrialized countries.

In addition, the development of standard or accredited detection methods, such as the International Standards Organization (ISO) standard for HAV and NoV detection using real-time polymerase chain reaction (PCR) (International Standards Organization, 2013, 2017), have allowed an increasing number of NoV or HAV infections to be definitively linked to contaminated food consumption.

While PCR detection is useful, it has also led to questions throughout the food industry about the interpretation of a positive test result in foods, as there is little information linking the presence of genomes to virus infectivity. However, given a virus' main route of transmission, its presence typically suggests that fecal contamination has occurred somewhere along the supply chain from farm to fork. This has left regulators and industry alike wondering how best to respond and react to positive findings (Stals et al., 2013). The recent NoV infectivity assay developed by Ettayebi et al. (2016) will by no means be employed on a routine basis, but the assay gives the possibility to determine the threshold of NoV genome copies that may pose a health threat. All stakeholders in the food industry agree that control measures for viruses throughout the food chain are required. However, much still needs to be understood with regards to the effectiveness of these controls and proper validation of their performance, whether it is the personal hygiene of food handlers, processing on of at risk foods or the interpretation and action on a positive test result in a virus testing program (ACMSF, 2015; EFSA, 2011).

The review will provide a general overview of foodborne viruses and their characteristics, responses to changes in environmental conditions, as well as a critical discussion on efficacy of technologies to control viral hazards. Technologies are summarized to provide insights into their mechanism of action for controlling viral hazards. Finally, a perspective on the application of science and technology for the industry is discussed.

In this respect, the information presented can be a useful resource for food safety decision making and provide guidance which will allow the industry to adopt more effective control measures for viruses in food processing.

2. Foodborne viruses – occurrence and risks

2.1. Description of foodborne viruses

Viruses are obligate intracellular parasites that require susceptible host cells for propagation and host infection. The extracellular infectious particle or virion is, from a structural point of view, very simple, consisting of a nucleic acid, either single stranded (ss) or double stranded (ds) DNA or RNA, surrounded by a protein coat. The presence or absence of an envelope, a lipid bilayer derived from host cell membranes and viral proteins, viruses are classified as enveloped or non-enveloped. Based on their size and shape, nucleotide composition and structure of the genome, as well as mode of replication, viruses are distributed into families, a few of which are grouped into orders (King et al., 2012).

A large number of different viruses may be found in the human gastrointestinal tract causing a wide variety of diseases (Table 2). Although any virus able to cause disease after ingestion could be potentially considered foodborne and/or waterborne, in practice most reported viral foodborne illnesses are gastroenteritis or hepatitis, caused by human NoV and HAV, respectively. However, other viral agents such as enteroviruses, sapoviruses, rotaviruses, astroviruses, adenoviruses, and Hepatitis E virus (HEV) have been implicated in food- and/or water-borne transmission of illness. Extremely high numbers of viruses may be shed in stools of patients suffering from gastroenteritis (inflammation of the gastrointestinal tract) or hepatitis, who may excrete up to 10^{13} and 10^{10} virus particles, respectively, per gram of stool (Costafreda et al., 2006; Ozawa et al., 2007; Caballero et al., 2013). The symptoms of viral gastroenteritis include nausea, vomiting and abdominal pain, and occasionally fever and headache (Arness et al., 2000). While bacterial gastroenteritis agents are usually responsible for the most severe cases, viruses such as NoV, are responsible for the