Food-borne diseases associated with frozen berries consumption: a historical perspective, European Union, 1983 to 2013

L Tavoschi (Lara.Tavoschi@ecdc.europa.eu)[1], E Severi[1], T Niskanen[1], F Boelaert[2], V Rizzi[2], E Liebana[2], J Gomes Dias[1], G Nichols[1,3], J Takkinen[1], D Coulombier[1]

1. European Centre for Disease Prevention and Control (ECDC), Stockholm, Sweden
2. European Food Safety Authority (EFSA), Parma, Italy
3. Current affiliation: Public Health England (PHE), Colindale, London, United Kingdom

Citation style for this article:
Tavoschi L, Severi E, Niskanen T, Boelaert F, Rizzi V, Liebana E, Gomes Dias J, Nichols G, Takkinen J, Coulombier D. Food-borne diseases associated with frozen berries consumption: a historical perspective, European Union, 1983 to 2013. Euro Surveill. 2015;20(29):pii=21193. Available online: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=21193

Article submitted on 12 February 2015/ published on 23 July 2015

Epidemiological investigations of outbreaks of hepatitis A virus (HAV) and norovirus (NoV) infections in the European Union/European Economic Area (EU/EEA) in the last five years have highlighted frozen berries as a vehicle of infection. Given the increasing berry consumption in the EU over the last decades, we undertook a review of the existing evidence to assess the potential scale of threat associated with this product. We searched the literature and four restricted-access online platforms for outbreak/contamination events associated with consumption of frozen berries. We performed an evaluation of the sources to identify areas for improvement. The review revealed 32 independent events (i.e. outbreak, food contamination) in the period 1983–2013, of which 26 were reported after 2004. The identified pathogens were NoV, HAV and *Shigella sonnei*. NoV was the most common and implicated in 27 events with over 15,000 cases reported. A capture–recapture analysis was performed including three overlapping sources for the period 2005–2013. The study estimated that the event-ascertainment was 62%. Consumption of frozen berries is associated with increasing reports of NoV and HAV outbreaks and contamination events, particularly after 2003. A review of the risks associated with this product is required to inform future prevention strategies. Better integration of the available communication platforms and databases should be sought at EU/EEA level to improve monitoring, prevention and control of food-borne-related events.

Introduction

In the past few years, several European Union/European Economic Area (EU/EEA) countries reported food-borne outbreaks and clusters of hepatitis A virus (HAV) and norovirus (NoV) infections. Analytical epidemiological studies conducted as part of the outbreak investigations identified frozen berries as the main vehicle of infection in several of them [1,2]. In these outbreaks, molecular typing of the isolated viral strains was pivotal in identifying a multinational dimension. Preliminary food trace back investigations revealed large scale distribution of these products in the EU/EEA area, and pointed to producers in countries both inside and outside of the EU/EEA. In 2013, outbreaks affecting an unprecedented large number of people in a number of countries have occurred in the EU/EEA and beyond, highlighting the role of frozen berries as a vehicle of infection [3-5].

The 2006 European Commission (EC) report on the soft fruit processing sector notes that the EU berry consumption has experienced a 4.5 fold increase in volume from 1988 to 2005. The import into the EU of frozen berries has seen a particularly steep increase in the last decade; this was also due to the growth in popularity of fruit-based products like smoothies, ice creams and yogurts [6]. The most traded soft fruits are strawberries, blackberries, blueberries, currants and raspberries. The main producers of berries imported into the EU are China, Morocco and Serbia while, within the EU, two thirds of berries are produced in Poland [6-8]. A recent scientific opinion published by the European Food Safety Authority (EFSA) on the risk of contamination of berries [7] highlights that this food commodity often receives no or only minimal processing. Berry production is labour-intensive and berries are often cultivated in small farms [6]. Contamination and cross-contamination via equipment, water (irrigation and washing) and particularly via food handlers have been identified as the main risk factors.

This paper provides a historical overview on contamination of frozen berries and the related outbreaks in the EU/EEA, through an analysis of the scientific literature and of relevant EU-operated databases. In addition we

Box

Methodology for the selection of records in the literature to review food-borne events associated with frozen berries consumption, EU/EEA, 1983–2013

PubMed

#1 "Disease Outbreaks"[Mesh] OR outbreak*[tiab]

#2 Berries[tiab] OR berry[tiab] OR "Fragaria"[Mesh] OR fragaria*[tiab] OR strawberr*[tiab] OR raspberr*[tiab] OR blackberr*[tiab] OR "Blueberry Plant"[Mesh] OR blueberr*[tiab] OR "Punicaceae"[Mesh] OR pomegranate*[tiab] OR cranberr*[tiab] OR "Vaccinium macrocarpon"[Mesh] OR "Ribes"[Mesh] OR gooseberr*[tiab] OR ribes[tiab] OR "black currant"[tiab] OR "black currants"[tiab] OR "Sambucus"[Mesh] OR sambucus[tiab] OR elderberr*[tiab] OR punicaceae[tiab] OR "Vaccinium vitis-idaea"[Mesh] OR "Vaccinium vitis idaea"[tiab] OR "lingon berry"[tiab] OR "lingon berries"[tiab] OR lingonberr*[tiab] OR ((juice[tiab] OR juices[tiab]) AND (fruit[tiab] OR fruits[tiab] OR "Fruit"[Mesh]))

#3 "Hepatitis A"[Mesh] OR "Hepatitis A virus"[Mesh] OR "hav"[tiab] OR "hepatitis a"[tiab] OR "hepatitis type a"[tiab] OR "Salmonella"[Mesh] OR "Salmonella Infections"[Mesh] OR salmonella[tiab] OR salmonellosis[tiab] OR salmonelloses[tiab] OR "Typhoid Fever"[Mesh]OR typhoid[tiab] OR typhoids[tiab] OR "enteric fever"[tiab] OR "enteric fevers"[tiab] OR "Norovirus"[Mesh] OR norovirus[tiab] OR noroviruses[tiab] OR "Norwalk virus"[tiab] OR "norwalk viruses"[tiab] OR NoV[tiab] OR hNoV[tiab] OR "Caliciviridae"[Mesh] OR Caliciviridae[tiab] OR calicivirus[tiab] OR "Escherichia coli"[Mesh] OR "Escherichia coli"[tiab] OR "E coli"[tiab] OR "e.coli"[tiab] OR "e. coli"[tiab] OR "Chagas Disease"[Mesh] OR "Trypanosoma cruzi"[Mesh] OR chagas[tiab] OR "trypanosoma cruzi"[tiab] OR "Cyclosporiasis"[Mesh] OR "Cyclospora"[Mesh] OR cyclosporiasis[tiab] OR cyclosporiases[tiab] OR cyclospora[tiab] OR cyclosporas[tiab] OR "Foodborne Diseases"[Mesh] OR "Foodborne Disease"[tiab] OR "Foodborne Diseases"[tiab] OR "Food borne Diseases"[tiab] OR "Food borne Disease"[tiab] OR "Foodborne illness"[tiab] OR "Foodborne illnesses"[tiab] OR "Food borne illness"[tiab] OR "Food borne illnesses"[tiab])

#4 #1 AND #2 AND #3

Embase

#1 outbreak*:ab,ti

#2 'berry'/exp OR berry:ti,ab OR berries:ti,ab OR 'strawberry'/exp OR fragaria*:ti,ab OR strawberr*:ti,ab OR 'raspberry'/exp OR raspberr*:ti,ab OR 'blueberry'/exp OR blueberry*:ti,ab OR 'blackberry'/exp OR blackberr*:ti,ab OR 'pomegranate'/exp OR pomegranate*:ti,ab OR punicaceae:ti,ab OR 'cranberry'/exp OR cranberr*:ti,ab OR 'Vaccinium macrocarpon':ti,ab OR 'gooseberry'/exp OR ribes:ti,ab OR 'black currant':ti,ab OR 'black currants':ti,ab OR 'Sambucus'/exp OR sambucus:ti,ab OR elderberr*:ti,ab OR 'lingonberry'/exp OR 'lingon berry':ti,ab OR 'lingon berries':ti,ab OR lingonberr*:ti,ab OR 'Vaccinium vitis idaea':ti,ab OR 'fruit juice'/exp OR ((fruit:ti,ab OR fruits:ti,ab) AND (juice:ti,ab OR juices:ti,ab))

#3 'hepatitis a'/exp OR 'hepatitis a virus'/exp OR hav:ab,ti OR 'hepatitis a':ab,ti OR 'hepatitis type a':ab,ti OR 'salmonella'/exp OR 'salmonellosis'/exp OR salmonella:ab,ti OR salmonellosis:ab,ti OR salmonelloses:ab,ti OR typhoid:ab,ti OR typhoids:ab,ti OR 'enteric fever':ab,ti OR 'enteric fevers':ab,ti OR 'norovirus'/exp OR 'norovirus infection'/exp OR norovirus:ab,ti OR noroviruses:ab,ti OR 'norwalk virus':ab,ti OR 'norwalk viruses':ab,ti OR nov:ab,ti OR hnov:ab,ti OR 'calicivirus'/exp OR 'calicivirus infection'/exp OR caliciviridae:ab,ti OR calicivirus:ab,ti OR 'escherichia coli'/exp OR 'escherichia coli infection'/exp OR 'escherichia coli':ab,ti OR 'e coli':ab,ti OR 'e.coli':ab,ti OR 'e. coli':ab,ti OR 'chagas disease'/exp OR chagas:ab,ti OR 'trypanosoma cruzi'/exp OR 'trypanosoma cruzi':ab,ti OR 'cyclospora'/exp OR 'cyclosporiasis'/exp OR cyclosporiasis:ab,ti OR cyclosporiases:ab,ti OR cyclospora:ab,ti OR cyclosporas:ab,ti OR 'food poisoning'/exp OR 'foodborne disease':ab,ti OR 'foodborne diseases':ab,ti OR 'food borne diseases':ab,ti OR 'food borne disease':ab,ti OR 'foodborne illness':ab,ti OR 'foodborne illnesses':ab,ti OR 'food borne illness':ab,ti OR 'food borne illnesses':ab,ti

#4 #1 AND #2 AND #3

evaluated the different data sources to identify potential areas for improving outbreak monitoring at EU/EEA level.

Methods

In order to review the available evidence of outbreaks of HAV and NoV and/or other relevant food-borne diseases associated with consumption of frozen berries, the scientific literature and relevant EU-based databases were searched.

Literature review

A comprehensive literature search was conducted in PubMed and Embase on 25 October 2013, using keywords and Medical Subject Heading (MESH) terms as described in the Box. No time, language or geographical limits were applied. Additional studies were identified through manual search of references and personal communications from experts in the EU/EEA Member States. Articles retrieved were screened by title/abstract and full text and included if (i) an outbreak/contamination event was reported; (ii) the vehicle of infection was identified to be frozen berries; (iii) at least one EU/EEA country was involved. All reports of outbreaks confined to non-EU/EEA countries were excluded. The same information obtained from notifications, were also extracted from included articles.

EU-based databases

Four relevant restricted-access online platforms exist at EU-level that collect information on contamination events and/or on human cases of diseases and outbreaks, namely: Epidemic Intelligence System for Food and Waterborne Diseases and Zoonoses (EPIS FWD), ECDC Threat Tracking Tool (TTT), European Food Safety Authority (EFSA) database on human food-borne

Table 1

European Union-operated databases and their purposes, historical perspective on food-borne events associated with frozen berries consumption, 1983–2013

EU-level database	Purpose
Epidemic Intelligence System for Food- and Waterborne Diseases and Zoonoses (EPIS FWD)	Communication platform of the ECDC for preliminary human health risk assessment of food and waterborne diseases, including notification of outbreaks and unusual increases of cases of disease at the national level. It was set up in 2010, and reporting is done on a voluntary basis [41].
ECDC Threat Tracking Tool (TTT)	ECDC database for epidemic intelligence purpose to keep track of events with potential public health impact at EU/EEA level. It was set up in 2005. An ECDC epidemic intelligence team is responsible for capturing relevant events into the database.
European Food Safety Authority (EFSA) database on human food-borne outbreaks	Database of Member States' annual reports on food-borne outbreaks in the EU/EEA. It was established in 2005, when reporting of food-borne outbreaks became mandatory in the EU/EEA.
Rapid Alert System for Food and Feed (RASFF)	European Commission communication platform to share information about existing threats/alerts posed by a food (or feed) item which is still on the market (e.g. pathogen-contaminated food item). It was set up in 1979. Reporting of any information about a serious health risk from food or feed is mandatory for EU/EEA countries (http://ec.europa.eu/rasff and http://ec.europa.eu/food/safety/rasff/index_en.htm).

ECDC: European Centre for Disease Prevention and Control; EEA: European Economic Area; EU: European Union.

outbreaks, Rapid Alert System for Food and Feed (RASFF). EFSA's scientific reports and opinions published on EFSA website were also consulted (Table 1).

The online platforms were searched by extracting all the notifications related to frozen berries involving at least one EU/EEA country (latest access date 31 October 2013) using the built-in search options. From each notification identified, the following information was extracted if available: time (year/month), country/ies involved, type of berry, number of associated human cases, result of molecular investigation and country of origin of the foodstuff. RASFF notifications of border control or other routine food safety checks were included in the analysis even in the absence of evidence of associated human cases, and listed in the output table as pathogen contamination incidents.

The Early Warning and Response System (EWRS) restricted platform of the EC was also searched, but not included in the analysis due to complete overlap with TTT and EPIS platforms.

Identification of independent events

We defined an event as: (i) notification of a food vehicle contamination associated with one or more outbreaks involving human cases; (ii) notification of a contamination of a food vehicle with no associated human cases (reported in Table 2 as a contamination incident). Once eligible entries were identified from the different sources, a manual record-linkage was performed based on the following variables: country reporting the outbreak; period (year, month); pathogen (species, genotype if available); vehicle (type of berry); reported cases. Each event identified can include one or more outbreaks and a cumulative number of reported cases.

A capture–recapture analysis [9] on three sources, namely the literature, RASFF, and EFSA database, was carried out for the period 2005 to 2013. The analysis was performed using three-source log-linear models, incorporating pairwise independencies in order to reduce possible bias. Multiple reports of the same event by any of the sources were treated as a single event in the analysis.

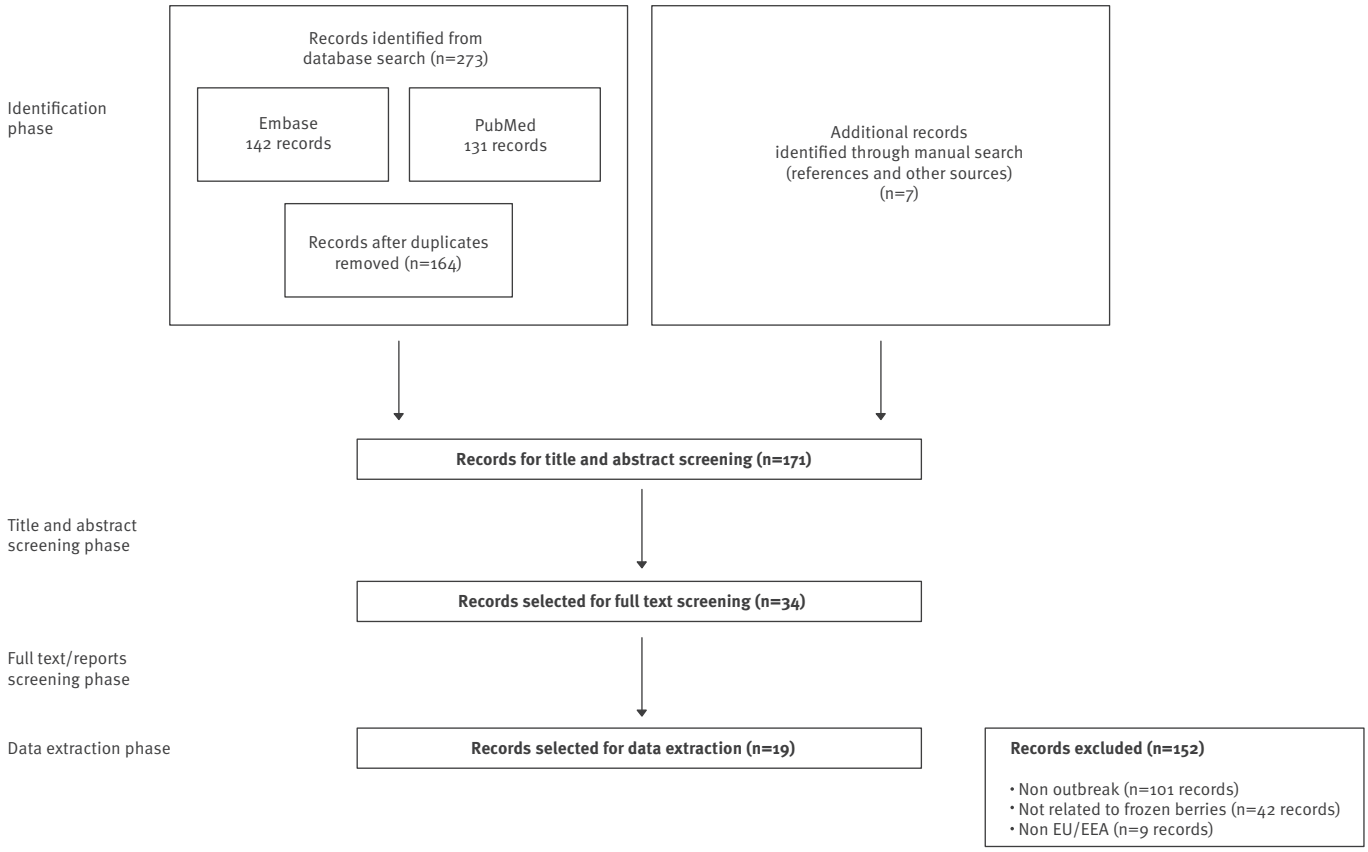
Results

Literature review

The literature search retrieved 273 articles: 131 from PubMed and 142 from Embase. After manual removal of duplicates and search for additional records, 171 were screened for the title and abstract, and 34 were

Figure 1

Flowchart showing the selection of records in the literature to review food-borne events associated with frozen berries consumption, EU/EEA, 1983–2013



EEA: European Economic Area; EU: European Union.

screened for the full text. Nineteen articles were included in the analysis (Figure 1).

Analysis of the reported events

The triangulation of the evidence collected from the various sources revealed 32 independent events, including 27 events with human cases reported, associated with contaminated frozen berries and five contamination incidents with no reported human cases. The identified pathogens were NoV, HAV and *Shigella sonnei*. The overall study period covered 30 years, from 1983 to 2013, however, 26 of 32 reported events, were between 2005 and 2013. The findings are summarised in Table 2.

Frozen berry contamination with NoV was implicated in 27 events during the period from 1998 to 2013. Of these 27, four were detected during routine food safety control and not associated, according to the available evidence, with human cases. Three of these four events occurred in 2013 and resulted in border rejection of the food consignment or in product recall. The remaining 23 events were distributed over a 15-year period from 1998 to 2013, and caused almost 14,000 reported human cases in 70 outbreaks in six EU countries, namely Denmark, Finland, France, Germany, the Netherlands and Sweden [2,10-19]. The frozen berries implicated as food vehicles in 23 of 27 of the reported outbreak events were frozen raspberries.

HAV contamination of frozen berries was first reported in an outbreak in 1983 in the United Kingdom [20], although there had been previous suggestions of associations [21]. However, there have been no reports between then and 2012–2013 when two multinational outbreaks occurred. The first outbreak affected four Nordic countries and was associated with the consumption of frozen strawberries; the second outbreak affected Italy and 12 additional EU/EEA countries and was associated with the consumption of frozen mixed berries [1,20,22-25]. The number of cases associated with these two events is estimated to be well above 1,500.

Finally, a *Shigella sonnei* outbreak linked to frozen mixed berries was reported to have affected 21 people in Sweden in 1996.

Analysis of the information sources

When the sources of information were taken into consideration, 12 out of 32 events were reported through RASFF only, five events were reported in the literature

Table 2

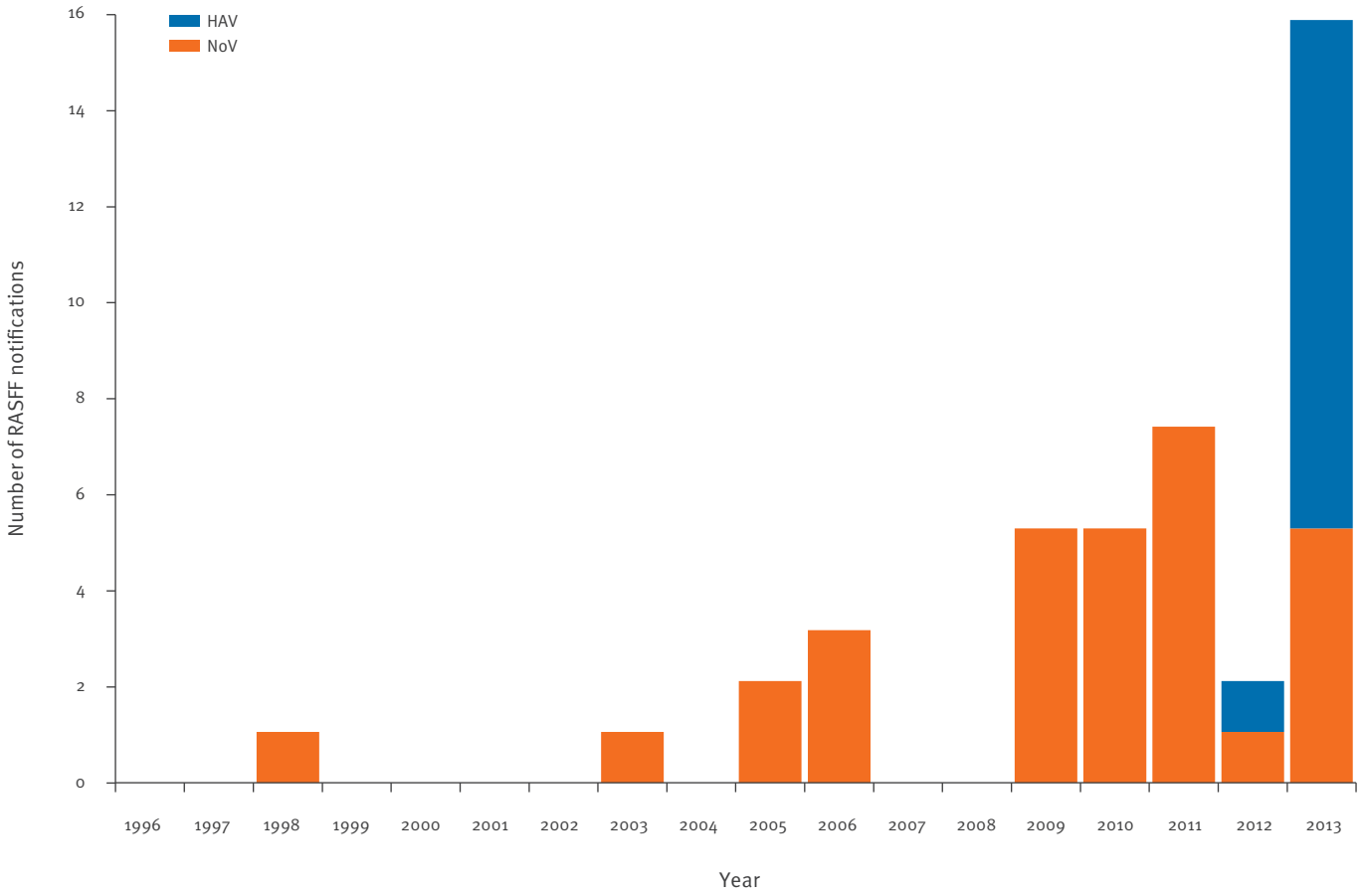
Reported outbreaks and contamination incidents with food-borne pathogens associated with frozen berries in the EU/EEA, 1983–2013

Listing of independent events	Source	Year	Pathogen	Vehicle	Number of cases reported	Number of reported outbreaks	Affected country/ies	Country/ies of origin of food vehicle
1	Literature [20]	1983	HAV	Frozen raspberries	24	1	United Kingdom	na
2	RASFF	1996	*Shigella sonnei*	Frozen mixed berries	21	1	Sweden	na
3	Literature [10,42]	1998	NoV	Frozen raspberries	509	1	Finland	na
4	RASFF	1998	NoV	Frozen raspberries	265	2	Sweden, Finland	Serbia, Montenegro
5	Literature [11]	2001	NoV	Frozen raspberries	30	1	Sweden	na
6	RASFF	2003	NoV	Frozen raspberries	>50	1	Sweden	Serbia, Montenegro
7	Literature [12]	2005	NoV	Frozen raspberries	75	1	France	na
8	TTT, RASFF, Literature [13,14]	2005	NoV	Frozen raspberries	>1,000	6	Denmark	Poland
9	Literature [15]	2005	NoV	Frozen blueberries	241	1	Germany	na
10	TTT, RASFF	2006	NoV	Frozen raspberries	25	1	Denmark	Serbia, Montenegro
11	TTT, RASFF, Literature [16,43]	2006	NoV	Frozen raspberries	43	4	Sweden	China
12	RASFF	2006	NoV	Frozen raspberries	45	1	The Netherlands	Chile
13	EFSA	2007	NoV	Frozen raspberries	9	1	Denmark	na
14	RASFF, EFSA, Literature [17-19]	2009	NoV	Frozen raspberries	1,093	22	Finland	Poland
15	RASFF, EFSA	2009–2010	NoV	Frozen raspberries	96	9	Denmark, Sweden	Serbia, Bosnia and Herzegovina
16	EFSA	2010	NoV	Frozen raspberries	60	1	Denmark	na
17	EFSA	2010	NoV	Frozen raspberries	133	2	Finland	na
18	RASFF	2010	NoV	Frozen raspberries	>1	1	Sweden	Poland
19	RASFF, EFSA	2011	NoV	Frozen raspberries	8	1	Denmark	China
20	RASFF	2011	NoV	Frozen raspberries	NA contamination incident	NA	Finland	Serbia
21	RASFF, EFSA	2011	NoV	Frozen raspberries	201	8	Denmark	Serbia
22	EFSA	2011	NoV	Frozen raspberries	52	2	Denmark	na
23	EFSA	2011	NoV	Frozen raspberries	18	1	Germany	Germany
24	TTT, RASFF, EFSA, Literature [2]	2012	NoV	Frozen strawberries	10,950	1	Germany	China
25	RASFF	2012	HAV	Frozen strawberries	NA contamination incident	NA	Belgium	China
26	EPIS FWD Literature [1,22]	2012–2013	HAV	Frozen strawberries	103	1	Finland, Denmark, Sweden,Norway	Egypt, Morocco
27	EPIS FWD, RASFF, Literature [23-25]	2013	HAV	Frozen mixed berries	>1,000	1	France, Italy,Ireland, the Netherlands, United Kingdom	Poland, Bulgaria
28	RASFF	2013	NoV	Frozen strawberries	NA contamination incident	NA	Lithuania	China
29	RASFF	2013	NoV	Frozen strawberries	NA contamination incident	NA	Denmark	China
30	RASFF	2013	NoV	Frozen raspberries	NA contamination incident	NA	The Netherlands	Poland
31	RASFF	2013	NoV	Frozen raspberries	29	1	Finland	Poland
32	RASFF	2013	NoV	Frozen raspberries	13	1	Denmark	Poland, Serbia

EEA: European Economic Area; EPIS FWD: Epidemic Intelligence System for Food and Waterborne Diseases and Zoonoses; EU: European Union; HAV: hepatitis A virus; na: not available; NA: not applicable; NoV: norovirus; RASFF: Rapid Alert System for Food and Feed; TTT: Threat Tracking Tool.

Figure 2

Distribution of number of RASFF notifications for norovirus and hepatitis A virus contamination in frozen berries, by year and implicated pathogen, EU/EEA, 1996–2013 (n=42)



HAV: hepatitis A virus; NoV: norovirus; RASFF: Rapid Alert System for Food and Feed.

only, and five events were reported only through EFSA. Finally, 10 events were reported by more than one source, including three events notified in EPIS FWD in the period from 2010 to 2013. Twenty-one events were linked to at least one RASFF notification, encompassing the three identified pathogens in the period from 1996 to 2013.

The number of RASFF notifications linked to contaminated frozen berries has increased over time, as shown in Figure 2 below. Among the events reported, five were linked to more than one RASFF notification, and up to 10 for one single multinational event (event number 27 in Table 2). The cumulative number of RASFF notifications was 42.

The geographic distribution of events shows a specific pattern, with countries affected by outbreaks of NoV and/HAV associated with the consumption of contaminated frozen berries being reported predominantly in Nordic countries, and in particular Denmark, Sweden and Finland (Figure 3). The food trace-back activities have pointed to Serbia, Poland or China as the country of origin of the implicated berries in 19 of the events (Figure 4).

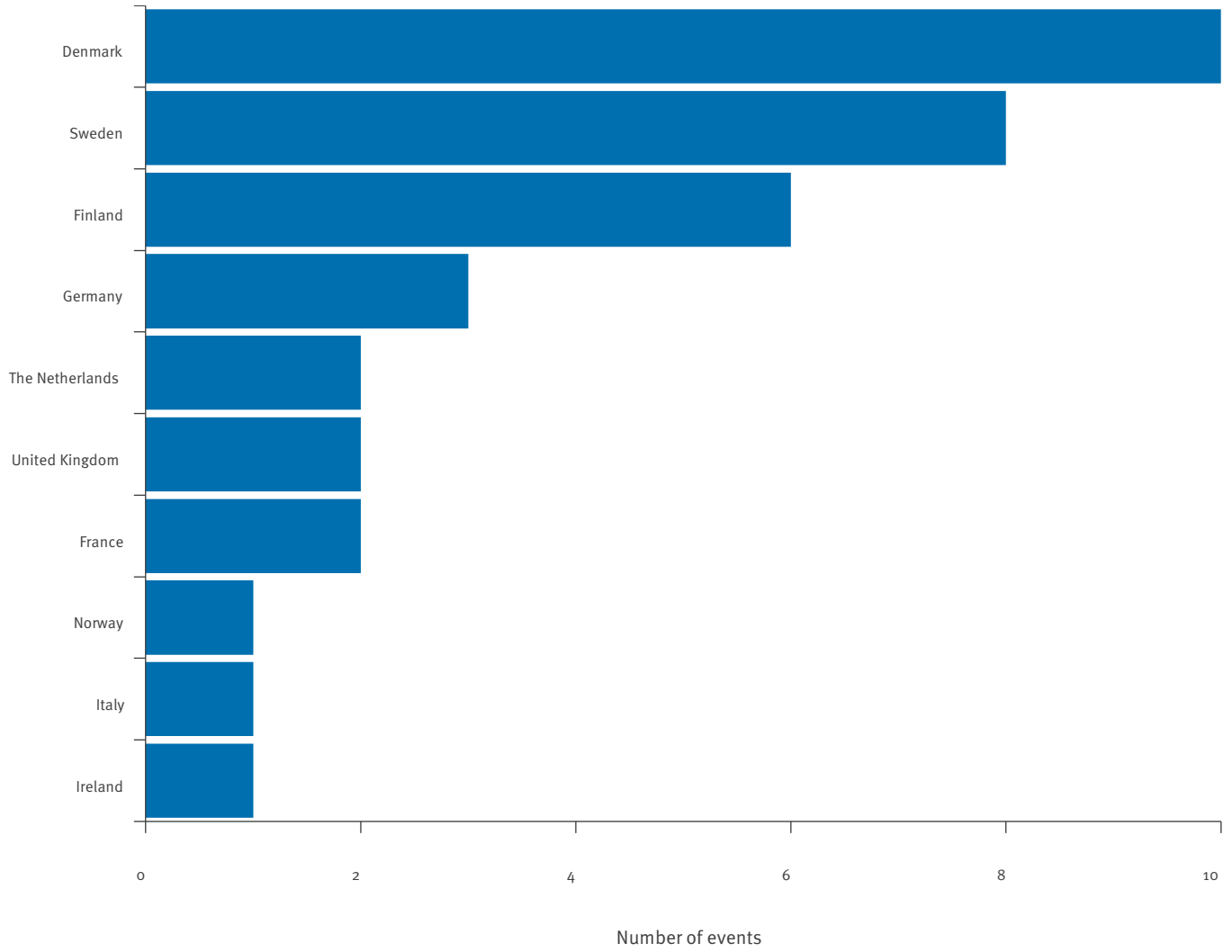
Frozen raspberries were the implicated food in 24 of the 32 events. For 23 of these 24 outbreaks, the isolated pathogen was NoV. According to RASFF notifications, contaminated raspberries are produced in several different countries. However, frozen strawberries produced in China were implicated in four of the five events associated with frozen strawberries.

Capture re-capture study

A capture–recapture analysis was performed including literature, RASFF and EFSA in the period from 2005 to 2013. These three independent sources identified a cumulative total of 26 unique events. The log-linear model used gave an estimate of 42 (95% confidence interval: 20–64) independent events occurring in the period from 2005 to 2013. The completeness of reported independent events can be estimated at 21.4% for the literature, 23.8% for the source in EFSA, and 42.9% for RASFF. The ascertainment of events, defined as reported outbreaks and contamination incidents, can be estimated at 61.9% in the period from 2005 to 2013.

Figure 3

Distribution of number of events[a] by country of occurrence, EU/EEA, 1983–2013 (n=32 events)



EEA: European Economic Area; EU: European Union.

[a] One event may be associated with more than one country of occurrence (see Table 2).

Discussion

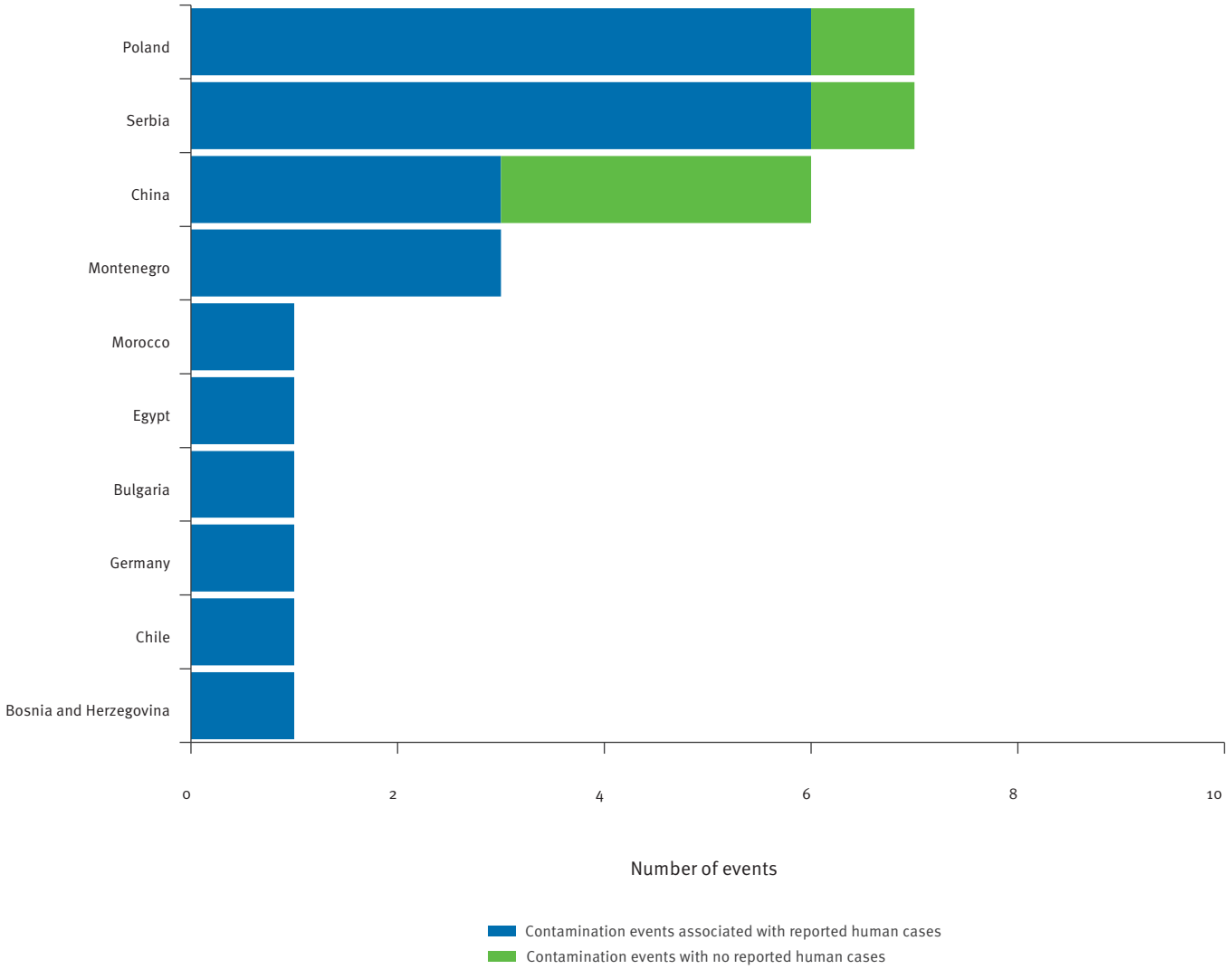
We reviewed contamination events of food-borne pathogens in frozen berries. The review combined different sources such as scientific literature and restricted access EU platforms. With the exclusion of one event associated with contamination with *Shigella sonnei*, events were due to contamination with NoV (27 events) and HAV (four events).

We identified 32 contamination events in a 30-year period, of which 26 occurred after 2004. This rise in number of reported outbreaks of NoV and HAV associated with consumption of frozen berries could be due to several concomitant factors. Increased likelihood of reporting over time and development of appropriate online platforms need to be considered alongside possible boosted interest in the scientific community. Technical developments in the detection of pathogens in food have resulted in the identification of implicated food vehicles with an increased accuracy over time [26-29]. The evolving molecular typing techniques have allowed matching food and human isolates and the identification of large multinational outbreaks sharing a common source [1,2,23]. The increase of RASFF notifications for contaminated frozen berries provides additional evidence on the rise in large contamination events. In 2013, several RASFF notifications were linked to a large multinational HAV outbreak associated with mixed frozen berry consumption in Italy and 12 additional EU/EEA countries [23-25]. This indicates the extensive environmental and trace back investigations performed by the affected countries when experiencing a large food-borne outbreak.

Liberalisation of markets and increased consumption of 'healthy' and raw food, such as berries, has increased the production and subsequently the risk of exposure to NoV and HAV for the EU population [6]. In 2013, three RASFF notifications for NoV contaminated berries were issued following border or other routine

Figure 4

Distribution of number of events in EU/EEA, by place of origin of the implicated berries, 1996–2013 (n=32 events[a])



EEA: European Economic Area; EU: European Union.

[a] Ten events missing information on the place of origin of the implicated berries.

Data source: European Food Safety Authority (EFSA); Epidemic Intelligence System (EPIS); Literature review; Rapid Alert System for Food and Feed (RASFF); Threat Tracking Tool (TTT).

food safety controls. This might have been related to the EU regulation [30] issued by the EC in 2012 to intensify the level of official controls on imports of specific food items of non-animal origin, including checks for NoV and HAV in strawberries from China.

Our review highlights the higher frequency of NoV outbreaks compared with HAV in the EU/EEA in the past decades. Although the two viruses share some common features, such as low dose infectivity and ability for long survival in the environment, HAV appears to be associated with a lower number of reported cases. This may be due in part to prevalence of individuals with long-lasting immunity after infection or vaccination, a high proportion of asymptomatic HAV infections or, alternatively, to challenging recognition of outbreaks and their association with a particular food item due to the long HAV incubation period and recall bias [31].

Our review identified one single event associated with Shigella in 1996. Although this does not appear to be a common health risk associated with the consumption of frozen berries, prevention and control measures should also include this pathogen.

There were some limitations in our study approach. We did not perform a systematic review of the available evidence. Hence some records may have not been retrieved. The manual record-linkage based on multiple variables may have resulted in imprecise estimates of the number of independent events reported in the study period. In addition, the number of human cases associated with each event may be affected by considerable under-reporting, typical of self-limiting gastrointestinal diseases and of asymptomatic manifestation of disease.

The different periods during which the sources have been operating and the different reporting practices may have impacted on the information retrieval, especially in the earlier decades. Comparison was also limited, as some of the EU-based platforms were introduced from 2005 onwards. Moreover, while reporting to the RASFF or EFSA database is mandatory for EU Member States, this is not the case for the other sources included in the analysis, resulting in reporting or publication bias. A more in-depth analysis of the grey literature such as national public health institutes reports, may have allowed more events to be retrieved, including a larger fraction of outbreaks with a national dimension, particularly from earlier years covered by our review.

As shown in the capture–recapture study, as many as 38% (16/42) of the estimated independent events, which occurred during the period 2005–2013, were not reported by any of the study sources. Although the accuracy of the capture-recapture study relies on an assumption of independence between the different sources, as well as on the correct identification of independent events, it suggests an appreciable level of incompleteness. The reasons why the investigated data sources were incomplete could not be disclosed by the present study, and was not one of the study objectives. Food-borne outbreak reporting systems at the national level are not harmonised among EU/EEA countries. The differences in the number and type of reported outbreaks may indicate differences in the sensitivity of the national systems in identifying and investigating food-borne outbreaks. These differences may not necessarily reflect the level of food safety in Member States.

The findings from this review are in line with two recent publications from EFSA [7,32]. EFSA developed an ad hoc model to identify and rank specific food/pathogen combinations most often linked to human cases originating from food of non-animal origin (FoNAO) in the EU, using seven criteria: strength of associations between food and pathogen, incidence of illness, burden of disease, dose-response relationship, consumption, prevalence of contamination and pathogen growth potential during shelf-life [32]. The assessment is based on the analyses of EU food-borne outbreaks reported to EFSA and associated with FoNAO in 2007–2011. The highest number of food-borne outbreaks was reported for the combination of NoV and raspberries. According to the model, NoV and raspberries ranked fourth among top groups of food/pathogen combinations. NoV and other berries ranked fifth. The model, however, does not distinguish between fresh and frozen berries. The resulting EFSA's Biological Hazards Panel (BIOHAZ) opinion [7] focused on noroviruses in frozen berries, and specifically assessed risk factors in the production chain and proposes adequate mitigation measures. If properly implemented, many of these measures are likely to have a positive impact on prevention of HAV contamination. However, the best and simplest preventive measure at the farm level seems to be hand washing after using the toilet [33].

The route by which fresh and frozen berries become contaminated is not fully understood. The three pathogens causing the outbreaks are likely to come from human sources. Manually picked fruits such as soft berries are at great risk of viral contamination if the quality of farming practices, e.g. worker hygiene during farming and harvesting, is insufficient. Contamination may also derive from poor quality irrigation water and spraying of berry crops [3,7,17,34]. Frozen as compared with fresh berries, may lead to larger scale contamination due to processing routines such as mixing batches of different origin during freezing and before packaging. As contamination of raspberries with different NoV genotypes has been documented, large batches of product for export may come from different farms [2,3,14,17]. The consequently uneven distribution of contaminated berries may result in poor detection of viruses in food samples undergoing routine food safety checks. The detection of these viruses in contaminated food vehicles is further hampered by the absence of a robust, quantitative method for sampling, concentration and analysis, the low levels of contamination and the effect of inhibitory materials for RT-PCR detection [3,26,27,35-37]. These factors may have impacted on the capacity to identify, and subsequently report, outbreaks or contamination events involving frozen berries, particularly in the earlier decades of the study period.

Although the size of berry farms varies broadly across the EU, small-scale farming is common. Together with wild-picked berries, berries from these farms have been considered to be more vulnerable for HAV and NoV contamination. Nevertheless, there is no evidence of association between farm size and risk of contamination. In addition, small-scale production, as well as inadequate labelling of the site of production, impacts the traceability of batches from wholesalers to the farm level [3,38].

According to several studies, decontamination of berries proves difficult as the ability to survive of enteric viruses on frozen berries is quite long, with marginal reduction of the infectivity even after several months of storage [39,40]. Considering the long shelf-life and the wide distribution of these products, contaminated batches may result in a long-term source of outbreaks of a national or multinational size. In consideration of this, and due to repeated NoV and HAV outbreaks related to frozen berries, some countries have implemented risk communication interventions and recommended to heat-treat frozen berries before use, for one to three minutes [3].

We presented evidence for an increasing number of outbreaks of HAV and NoV associated with the consumption of frozen berries reported in the EU/EEA, predominately in the past 10 years. In consideration of the

increasing consumption of berries in the EU/EEA [6], and such an emerging public health risk [7], a review of the risks for NoV and HAV contaminations associated with farming, picking, processing and distribution of fresh and frozen berries is needed. In particular, such a risk assessment would provide the necessary evidence to assess the adequateness of existing food safety regulations on the production and handling of berries to ensure safe products are on the market (and trade) with respect to contamination with NoV and HAV. From a public health perspective, risk communication messages such as heat-treating frozen berries before consumption should be re-iterated. Recommendations for HAV vaccination for habitual consumers of frozen berries may also be considered, especially for high-risk individuals.

In addition, to enhance the detection, control and investigation of outbreaks due to contaminated berries, and to support the assessment of the health risks, a better integration of the available communication platforms and databases should be sought at EU/EEA level to improve coordinated data collection and reporting.

Acknowledgements

The authors would like to acknowledge Irene Munoz Guajardo for performing the literature search.

Conflict of interest

None declared.

Authors' contributions

LT wrote the manuscript. ES contributed extensively to the manuscript drafting. TN, VR, FB and EL contributed with comments and revised the manuscript. ES and LT collected the data and performed the analysis. GN, TN, VR, FB and EL contributed to data collection. JGD performed the capture-recapture analysis. JT and DC reviewed the manuscript.

References

1. Nordic Outbreak Investigation Team C. Joint analysis by the Nordic countries of a hepatitis A outbreak, October 2012 to June 2013: frozen strawberries suspected. Euro Surveill. 2013;18(27):20520. http://dx.doi.org/10.2807/1560-7917.ES2013.18.27.20520 PMID:23870076
2. Mäde D, Trübner K, Neubert E, Höhne M, Johne R. Detection and Typing of Norovirus from Frozen Strawberries Involved in a Large-Scale Gastroenteritis Outbreak in Germany. Food Environ Virol. 2013;5(3):162-8. http://dx.doi.org/10.1007/s12560-013-9118-0 PMID:23888384
3. European Food Safety Authority (EFSA). Tracing of food items in connection to the multinational hepatitis A virus outbreak in Europe EFSA Journal 2014;12(9):186.
4. Collier MG, Khudyakov YE, Selvage D, Adams-Cameron M, Epson E, Cronquist A, et al.; Hepatitis A Outbreak Investigation Team. Outbreak of hepatitis A in the USA associated with frozen pomegranate arils imported from Turkey: an epidemiological case study. Lancet Infect Dis. 2014;14(10):976-81. http://dx.doi.org/10.1016/S1473-3099(14)70883-7 PMID:25195178
5. Severi E, Verhoef L, Thornton L, Guzman-Herrador BR, Faber M, Sundqvist L, et al. Large and prolonged food-borne multistate hepatitis A outbreak in Europe associated with consumption of frozen berries, 2013 to 2014. Euro Surveill. 2015;20(29):21192.
6. Commission of the European Communities. Commission staff working document - Annex to the report from the commission to the council and the European Parliament on the situation of the sector of soft fruits and cherries intended for processing: Review of the sector of soft fruits and cherries intended for processing in the EU. Brussels: Commission of the European Communities. 28 Jun 2006. Available from: http://ec.europa.eu/agriculture/publi/reports/fruitveg/softfruit/workdoc_en.pdf
7. European Food Safety Authority (EFSA). EFSA Panel on Biological Hazards. Scientific Opinion on the risk posed by pathogens in food of non-animal origin. Part 2 (Salmonella and Norovirus in berries). EFSA Journal. 2014;12(6):95.
8. Commission of the European Communities. ARCOTRASS Consortium. Serbia Country Report - Study on the State of Agriculture in Five Applicant Countries. Brussels: Commission of the European Communities. Dec 2006. Available from: http://ec.europa.eu/agriculture/analysis/external/applicant/synthesis_en.pdf
9. Hook EB, Regal RR. Validity of methods for model selection, weighting for model uncertainty, and small sample adjustment in capture-recapture estimation. Am J Epidemiol. 1997;145(12):1138-44. http://dx.doi.org/10.1093/oxfordjournals.aje.a009077 PMID:9199544
10. Ponka A, Maunula L, Von Bonsdorff CH, Lyytikainen O. Outbreak oof calicivirus gastroenteritis associated with eating frozen raspberries. Euro Surveill. 1999;4(6):66-9. PMID:12631898
11. Le Guyader FS, Mittelholzer C, Haugarreau L, Hedlund KO, Alsterlund R, Pommepuy M, et al. Detection of noroviruses in raspberries associated with a gastroenteritis outbreak. Int J Food Microbiol. 2004;97(2):179-86. http://dx.doi.org/10.1016/j.ijfoodmicro.2004.04.018 PMID:15541804
12. Cotterelle B, Drougard C, Rolland J, Becamel M, Boudon M, Pinede S, et al. Outbreak of norovirus infection associated with the consumption of frozen raspberries, France, March 2005. Euro Surveill. 2005 Apr;10(4):E050428 1. PMID: 16766816. Epub 2006/06/13.
13. Korsager B, Hede S, Boggild H, Bottiger BE, Molbak K. Two outbreaks of norovirus infections associated with the consumption of imported frozen raspberries, Denmark, May-June 2005. Euro Surveill. 2005;10(6):E050623 1. PMID: 16783103. Epub 2006/06/20.
14. Falkenhorst G, Krusell L, Lisby M, Madsen SB, Bottiger B, Molbak K. Imported frozen raspberries cause a series of norovirus outbreaks in Denmark, 2005. Euro Surveill. 2005;10(9):E050922.2.
15. Fell G, Boyens M, Baumgarte S. [Frozen berries as a risk factor for outbreaks of norovirus gastroenteritis. Results of an outbreak investigation in the summer of 2005 in Hamburg]. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz. 2007;50(2):230-6. http://dx.doi.org/10.1007/s00103-007-0142-9 PMID:17238056
16. Hjertqvist M, Johansson A, Svensson N, Abom PE, Magnusson C, Olsson M, et al. Four outbreaks of norovirus gastroenteritis after consuming raspberries, Sweden, June-August 2006. Euro Surveill. 2006;11(9):E060907 1. PMID: 17075140. Epub 2006/11/01.
17. Sarvikivi E, Roivainen M, Maunula L, Niskanen T, Korhonen T, Lappalainen M, et al. Multiple norovirus outbreaks linked to imported frozen raspberries. Epidemiol Infect. 2012;140(2):260-7. http://dx.doi.org/10.1017/S0950268811000379 PMID:21418716
18. Maunula L, Roivainen M, Keranen M, Makela S, Soderberg K, Summa M, et al. Detection of human norovirus from frozen raspberries in a cluster of gastroenteritis outbreaks. Euro Surveill. 2009;14(49). PMID: 20003905. Epub 2009/12/17.
19. Niskanen Taina KT, Pihlajasaari Annika,, Miettinen Ilkka SA, Johansson Tuula. Foodborne and waterborne outbreaks in Finland 2009. Finnish Food Safety Authority Evira. 2011.
20. Reid TMS, Robinson HG. Frozen raspberries and hepatitis A. Epidemiol Infect. 1987;98(1):109-12. http://dx.doi.org/10.1017/S095026880006177X PMID:3030789
21. Noah N. Foodborne outbreaks of hepatitis A. Med Lab Sci. 1981;38:428.
22. Gillesberg Lassen S, Soborg B, Midgley SE, Steens A, Vold L, Stene-Johansen K, et al. Ongoing multi-strain food-borne hepatitis A outbreak with frozen berries as suspected vehicle: four Nordic countries affected, October 2012 to April 2013. Euro Surveill. 2013;18(17):20467. PMID:23647625
23. Rizzo C, Alfonsi V, Bruni R, Busani L, Ciccaglione A, De Medici D, et al.; Central Task Force on Hepatitis A. Ongoing outbreak of hepatitis A in Italy: preliminary report as of 31 May 2013. Euro Surveill. 2013;18(27):20518. http://dx.doi.org/10.2807/1560-7917.ES2013.18.27.20518 PMID:23870075

24. Ricotta L, Montano C, Alfonsi V, Tosti ME, Bella A, Ciccaglione AR, et al. Hepatitis A outbreak in Italy, 2013: disentangling the role of risk factors associated with the disease. European Scientific Conference on Applied Infectious Disease Epidemiology (ESCAIDE); 5-7 November 2013; Stockholm: ECDC; 2013. p. 147.
25. Fitzgerald M, Rogalska J, Garvey P, O'Flanagan D, Thornton L. Hepatitis A genotype IA outbreak associated with products containing frozen berries, Ireland 2013. European Scientific Conference on Applied Infectious Disease Epidemiology (ESCAIDE); 5-7 November 2013; Stockholm: ECDC; 2013. p. 147.
26. Summa M, von Bonsdorff CH, Maunula L. Evaluation of four virus recovery methods for detecting noroviruses on fresh lettuce, sliced ham, and frozen raspberries. J Virol Methods. 2012;183(2):154-60. http://dx.doi.org/10.1016/j.jviromet.2012.04.006 PMID:22580195
27. Butot S, Putallaz T, Sánchez G. Procedure for rapid concentration and detection of enteric viruses from berries and vegetables. Appl Environ Microbiol. 2007;73(1):186-92. http://dx.doi.org/10.1128/AEM.01248-06 PMID:17085706
28. Butot S, Le Guyader FS, Krol J, Putallaz T, Amoroso R, Sánchez G. Evaluation of various real-time RT-PCR assays for the detection and quantitation of human norovirus. J Virol Methods. 2010;167(1):90-4. http://dx.doi.org/10.1016/j.jviromet.2010.03.018 PMID:20362008
29. Bresee JS, Widdowson MA, Monroe SS, Glass RI. Foodborne viral gastroenteritis: challenges and opportunities. Clin Infect Dis. 2002;35(6):748-53. http://dx.doi.org/10.1086/342386 PMID:12203173
30. Commission of the European Communities. Commission Implementing Regulation (EU) No 1235/2012 of 19 December 2012 amending Annex I to Regulation (EC) No 669/2009 implementing Regulation (EC) No 882/2004 of the European Parliament and of the Council as regards the increased level of official controls on imports of certain feed and food of non-animal origin. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:350:0044:0050:EN:PDF
31. Heymann D. Control of communicable diseases manual, 18th edition, Official report of the American Public Health Association. 2008.
32. European Food Safety Authority (EFSA). EFSA Panel on Biological Hazards (BIOHAZ Panel). Scientific Opinion on the risk posed by pathogens in food of non-animal origin. Part 1 (outbreak data analysis and risk ranking of food/pathogen combinations). EFSA Journal. 2013;11(1).
33. De Keuckelaere A. The issue of norovirus in leafy greens and raspberries. 6th Veg-i-Trade meeting; Pretoria, March 2014.
34. Maunula L, Kaupke A, Vasickova P, Söderberg K, Kozyra I, Lazic S, et al. Tracing enteric viruses in the European berry fruit supply chain. Int J Food Microbiol. 2013;167(2):177-85. http://dx.doi.org/10.1016/j.ijfoodmicro.2013.09.003 PMID:24135674
35. Love DC, Casteel MJ, Meschke JS, Sobsey MD. Methods for recovery of hepatitis A virus (HAV) and other viruses from processed foods and detection of HAV by nested RT-PCR and TaqMan RT-PCR. Int J Food Microbiol. 2008;126(1-2):221-6. http://dx.doi.org/10.1016/j.ijfoodmicro.2008.05.032 PMID:18579246
36. Papafragkou E, Plante M, Mattison K, Bidawid S, Karthikeyan K, Farber JM, et al. Rapid and sensitive detection of hepatitis A virus in representative food matrices. J Virol Methods. 2008;147(1):177-87. http://dx.doi.org/10.1016/j.jviromet.2007.08.024 PMID:17931710
37. Sánchez G, Bosch A, Pintó RM. Hepatitis A virus detection in food: current and future prospects. Lett Appl Microbiol. 2007;45(1):1-5. http://dx.doi.org/10.1111/j.1472-765X.2007.02140.x PMID:17594452
38. Food Standards Agency. Workshop: Global Chain Analysis of and Hepatitis A contamination of berry fruit supply chain. 2014.
39. Butot S, Putallaz T, Amoroso R, Sánchez G. Inactivation of enteric viruses in minimally processed berries and herbs. Appl Environ Microbiol. 2009;75(12):4155-61. http://dx.doi.org/10.1128/AEM.00182-09 PMID:19395576
40. Butot S, Putallaz T, Sánchez G. Effects of sanitation, freezing and frozen storage on enteric viruses in berries and herbs. Int J Food Microbiol. 2008;126(1-2):30-5. http://dx.doi.org/10.1016/j.ijfoodmicro.2008.04.033 PMID:18547667
41. Gossner C. ECDC launches the second version of the EPIS-FWD platform. Euro Surveill. 2013;18(27):20517. PMID: 23870080. Epub 2013/07/04.
42. Pönkä A, Maunula L, von Bonsdorff CH, Lyytikäinen O. An outbreak of calicivirus associated with consumption of frozen raspberries. Epidemiol Infect. 1999;123(3):469-74. http://dx.doi.org/10.1017/S0950268899003064 PMID:10694159
43. Lysén M, Thorhagen M, Brytting M, Hjertqvist M, Andersson Y, Hedlund KO. Genetic diversity among food-borne and waterborne norovirus strains causing outbreaks in Sweden. J Clin Microbiol. 2009;47(8):2411-8. http://dx.doi.org/10.1128/JCM.02168-08 PMID:19494060