



**HAL**  
open science

# Fishery discards do not compensate natural prey shortage in Northern gannets from the English Channel

Tangi Le Bot, Amélie Lescroel, Jérôme Fort, Clara Péron, Olivier Gimenez,  
Pascal Provost, David Grémillet

► **To cite this version:**

Tangi Le Bot, Amélie Lescroel, Jérôme Fort, Clara Péron, Olivier Gimenez, et al.. Fishery discards do not compensate natural prey shortage in Northern gannets from the English Channel. *Biological Conservation*, 2019, 236, pp.375-384. 10.1016/j.biocon.2019.05.040 . hal-02329861

**HAL Id: hal-02329861**

**<https://hal.science/hal-02329861>**

Submitted on 25 Oct 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

## **Fishery discards do not compensate natural prey shortage in Northern gannets from the English Channel.**

Tangi Le Bot<sup>1\*</sup>, Amélie Lescroël<sup>2</sup>, Jérôme Fort<sup>3</sup>, Clara Péron<sup>4</sup>, Olivier Gimenez<sup>1</sup>, Pascal Provost<sup>5</sup> & David Grémillet<sup>1,6</sup>

- 1- CEFE, CNRS, Univ Montpellier, Univ Paul Valéry Montpellier 3, EPHE, IRD, Montpellier, France
- 2- Point Blue Conservation Science, 3820 Cypress Drive, Suite 11, Petaluma, CA 94954, USA
- 3- Littoral Environnement et Sociétés (LIENSs), UMR 7266 CNRS-Université de La Rochelle, La Rochelle, France
- 4- Laboratoire d'Océanographie et du Climat, UMR 7159. 4 Place Jussieu 75005 Paris, France.
- 5- Ligue pour la Protection des Oiseaux, Réserve Naturelle Nationale des Sept-Iles, 22560 Pleumeur Bodou, France
- 6- Percy FitzPatrick Institute and DST-NRF Centre of Excellence at the University of Cape Town, Rondebosch, South Africa

\* Corresponding author

1 **Evaluation of methods for elution of HEV particles in naturally contaminated**  
2 **sausage, figatellu and pig liver**

3

4 **Catherine Hennechart-Collette, Audrey Fraisse, Laurent Guillier, Sylvie Perelle\*,**  
5 **Sandra Martin-Latil\***

6

7

8

9

10

11

12 **Université Paris-Est, Anses, Laboratory for food safety, F-94700 Maisons-Alfort,**  
13 **France.**

14

15

16

17 \* Corresponding author. Tel: +33 (0)1 49 77 28 24; fax: +33 (0)1 43 68 97 62.

18 *E-mail address:* [sandra.martin-latil@anses.fr](mailto:sandra.martin-latil@anses.fr) and [sylvie.perelle@anses.fr](mailto:sylvie.perelle@anses.fr)

19

20

## 21 **Abstract**

22 Foodborne transmission of HEV is a growing public health concern in industrialised  
23 countries, where the disease is mainly autochthonous, caused by zoonotic HEV of  
24 either genotype 3 or 4. Foodstuffs containing pig's liver were suspected on several  
25 occasions to be the cause of autochthonous cases of HEV infection, while the  
26 transmission was associated with animal contact and the ingestion of raw or  
27 uncooked meat, especially liver. In assessing the risk related to the presence of HEV  
28 in food, detection methods were previously developed but HEV detection rates seem  
29 to vary with the type of samples and methods. The ISO procedures (15216-1:2017)  
30 only propose standard methods for quantifying NoV and HAV in bottled water,  
31 shellfish, vegetables and soft fruit. As foodstuff containing pig liver can be  
32 contaminated with HEV internally, an efficient virus extraction procedure is required.  
33 The aim of this study was to evaluate six methods for their efficiency in releasing  
34 HEV viral particles from figatelli, pig liver sausages and liver samples previously  
35 tested positive for the presence of HEV. The ratio weight to volume of elution buffer  
36 (1:5) and the FastPrep®-24 homogenizer showed to significantly improve the  
37 quantity of HEV genomes released per gram of figatelli and pig liver sausages. To our  
38 knowledge, this study is the first to evaluate several methods for elution of HEV  
39 particles from naturally contaminated pig liver products, and may be extended for  
40 quantifying other viral genomes from food of animal origin.

41

## 42 **1. Introduction**

43 Hepatitis E virus (HEV) is a positive single-stranded RNA virus classified in the genus  
44 Orthohepevirus within the family *Hepeviridae* (Emerson et al., 2004, Khuroo et al.,  
45 2016, Smith et al., 2013). HEV has been recognised as a cause of acute hepatitis

46 occurring during waterborne outbreaks in most parts of Asia and Africa where it is  
47 endemic and primarily spread by the faecal-oral route (World Health Organization,  
48 2013). In the industrialized countries, HEV infection leads to sporadic and  
49 autochthonous cases of acute viral hepatitis and has increased as a result of  
50 zoonotic transmission from the animal reservoir. Among the major HEV genotypes,  
51 the genotypes G3 and G4 are known to be zoonotic.

52 Several cases of hepatitis E have been reported after consumption of contaminated  
53 raw or undercooked meat, liver, and liver sausages from infected animals (eg: wild  
54 boar, pig) (Colson et al., 2010; Deest et al., 2007; Tamada et al., 2004; Yazaki et al.,  
55 2003; Masuda et al., 2005; Tei et al., 2003). A previous study confirmed that HEV  
56 detected in pork liver sausage is infectious, highlighting the risk for consumers (Berto  
57 et al., 2013). To date, there is no standardised protocol for the detection of HEV in  
58 meat products. Various protocols have been published and applied to detect HEV on  
59 soft fruits and vegetables, in water, shellfish, and pork products (Brassard et al.,  
60 2012; Leblanc et al., 2010; Martin et al., 2012; Thesale et al., 2010; Grodzki et al.,  
61 2014; Renou et al., 2014; Wilhelm et al., 2014; Martin-Latil et al., 2014; Di Bartolo et  
62 al., 2015; Szabo et al., 2015; Terio et al., 2017). Given that foodstuffs containing pig  
63 liver have an animal origin, the virus extraction is a crucial step and requires an  
64 efficient grinding for releasing HEV from food with an internal contamination.

65 The aim of this study was to evaluate six methods for their efficiency to eluate viral  
66 particles of HEV from naturally contaminated food samples containing raw pig liver  
67 and to determine the most efficient **method** for extracting HEV from figatelli, pig liver  
68 sausages and liver.

69

## 70 **2. Materials and methods**

## 71 **2. 1. Food samples containing pig liver**

72 Pig liver samples were collected in the framework of a national official surveillance  
73 plan organised by the French Ministry of Agriculture, Food and Forestry in 2011,  
74 according to EC Regulation 882/2004 and EC Directive 2003/99/EC (2003; 2004). Of  
75 the 400 samples qualitatively analysed to detect HEV (Pavio et al., 2014), 70  
76 samples were quantitatively analysed (Martin-Latil et al., 2014) and conserved at -  
77 80°C. One liver, one figatellu and one sausage found positive for the presence of  
78 HEV genomes were selected for this study because of their high (>10<sup>6</sup> genome  
79 copies per gram) HEV contamination levels.

80

## 81 **2.2. Sample processing for recovering HEV**

82 Six elution methods were tested for recovering HEV from sausage, figatellu and liver.  
83 Among them, the reference method B was the one previously developed in the  
84 framework of a French monitoring program (Martin-Latil et al., 2014). Figure 1 gives  
85 an overview of these six methods. Details of the extraction methods are described  
86 below.

87

### 88 **2.2.1 Method of elution and viral RNA extraction**

89 Three parameters were tested (weight of food sample, ratio of weight-of-  
90 sample/elution-volume and homogenisation method) as described in Figure 1.

91 For each sample of sausage and figatellu, fat was removed manually with a surgical  
92 blade. All samples were separated into 3 g (Methods A, B, D, E) or 10 g (Methods C  
93 and F) portions, and were homogenised in 15 mL (Methods D and E), 30 mL  
94 (Methods A and B), 50 mL (Method F) or 100 mL (Method C) of distilled water with

95 the FastPrep®-24 tissue (Methods A and D) and cell homogeniser (MP  
96 Biochemicals) or with the Stomacher 400 apparatus (Fisher Bioblock Scientific,  
97 Illkirch, France) (Methods B, C, E, F). For homogenisation with the stomacher  
98 apparatus, food samples were placed in a 400 mL polypropylene bag containing a  
99 filter compartment and were homogenised in distilled water using a stomacher  
100 apparatus at a normal velocity of 230 rpm for 2 min as previously described (Fumian  
101 et al.,2009; Martin-Latil et al., 2014). For the FastPrep®-24 homogeniser, samples  
102 were transferred to a 50 mL tube containing lysing matrix D ceramic beads (MP  
103 Biochemicals, Solon, OH, USA) and were homogenised using FastPrep®-24 tissue  
104 and cell homogeniser for 20 sec at 6 ms<sup>-1</sup>.

105 Viral elution was carried out by incubating all samples for 10 min at room temperature  
106 with constant shaking regardless the homogenisation method used. The tube sample  
107 containing lysing matrix D ceramic beads was transferred to a 400 mL polypropylene  
108 bag containing a filter compartment. Then, all filtrates were transferred to a 50 mL  
109 centrifuge tube and centrifuged at 8,000 g for 15 min at 4°C to be clarified for  
110 removal of particles of debris.

111 One mL of filtered homogenates was processed on a NucliSens® easyMAG™  
112 platform (bioMérieux) for viral RNA extraction using the “off-board Specific A”  
113 protocol according to the manufacturer's instructions.

114 Nucleic acids were eluted in 70 µL of elution buffer, aliquoted and stored at -80°C.

115 The experimental step from elution to RNA extraction was performed five times. The  
116 same RNA extract (undiluted and 10-fold diluted) was analysed in duplicate with RT-  
117 qPCR assay to detect and quantify HEV. Results were expressed as log genome  
118 copies of HEV per gram.

119

### 120 **2.3.2 Primers and probes**

121 The primers and the TaqMan® probe targeting the ORF2/ORF3 overlapping region  
122 of HEV used in this study were adapted from the published model by Jothikumar et  
123 al. (2006). The sequence of the primer pairs and the TaqMan probes used was as  
124 follows: the sense primer (HEV-5260-F) was: 5'-CGGTGGTTTCTGGGGTGAC-3', the  
125 antisense primer (HEV-5330-R) was: 5'-AGGGGTTGGTTGGATGAATATAG-3' and  
126 the TaqMan probe (HEV-5280-T) was: 5'-ROX-GGGTTGATTCTCAGCCCTTCGC -  
127 BHQ2-3'.

128

### 129 **2.3.3 RT-qPCR conditions**

130 Viral genomes were detected using one-step RT-qPCR, which was performed in  
131 duplicate on the CFX96™ real-time PCR detection system from Bio-Rad (Marnes-la-  
132 Coquette, France).

133 Reactions were performed in a 25 µL reaction mixture containing 1×RNA  
134 UltraSense™ master mix and 1.25 µL of RNA Ultrasense™ enzyme mix, which are  
135 components of the RNA UltraSense™ One-Step Quantitative RT-PCR System  
136 (Fisher Bioblock Scientific, Illkirch, France), 2 U RNase inhibitor (Applied  
137 Biosystems), 5 µg of bovine serum albumin (Ambion), 600 nM of HEV-5260-F  
138 forward primer, 600 nM of HEV-5330-R reverse primer, 250 nM of HEV-5280-T probe  
139 and 5 µL of RNA extract. Positive controls containing RNA extracted from virus  
140 suspensions and a negative control containing all the reagents except the RNA  
141 template were included with each set of reaction mixtures. The one-step RT-qPCR  
142 programme was 60 min of reverse transcription of RNA at 55°C, followed by a 5 min  
143 denaturation step at 95°C, and finally 45 cycles of 15 sec at 95°C, 1 min at 60°C and  
144 1 min at 65°C. The fluorescence was recorded by the apparatus at the end of the



145 elongation steps (1 min at 65°C) for each amplification cycle. All samples were  
146 characterised by a corresponding Cycle threshold (Ct) value. Negative samples gave  
147 no Ct value.

148 The slopes (S) of the regression lines were used to calculate the amplification  
149 efficiency (E) of the RT-qPCR reactions, according to the formula:  $E = 10^{|-1/s|} - 1$ .

150 To establish the standard curves, the genomic stock of HEV viral RNA was obtained  
151 as previously described by Martin-Latil et al. (2014) and had a titre of approximately  
152  $1.75 \times 10^6$  genome copies/mL. The recovery quantity of HEV in food samples was  
153 calculated by reference to the corresponding standard curves obtained from ten-fold  
154 dilution of the titrated clarified suspension stock of HEV.

155

#### 156 **2.3.4 Statistical analysis**

157 The quantitative data of HEV recovered with different elution methods from naturally  
158 contaminated figatellu, sausage and liver are expressed in log genome copies per g  
159 follow a normal distribution  $N(\mu, \sigma)$ . The Normal distribution is completely  
160 characterized by the sample mean ( $\mu$ ) and sample standard deviation ( $\sigma$ ).

161 The standard normal distribution curve of data is a symmetrical bell-shaped. The  
162 peak is located at the sample mean  $\mu$  and its height indicates weather values in the  
163 population fall near the mean value or not. The width of the bell is determined by the  
164 population standard deviation ( $\sigma$ ) that measures the spread of a data distribution.

165 A one-way analysis of variance (ANOVA) was further performed with Statgraphics  
166 Centurion XVII software to evaluate the influence of the elution method on the  
167 recovered quantity of HEV. Quantitative data obtained from undiluted and 10-fold  
168 diluted RNA samples were taken into account for this statistical analysis. The result  
169 of the ANOVA is a p value associated with the hypothesis that the mean recovery

170 quantities of all groups (expressed as percentages) were the same. Because the  
171 HEV recovered quantities were statistically different depending on the elution method  
172 used (ANOVA,  $p < 0.05$ ), a multiple comparison procedure was applied to determine  
173 which elution method provided the highest recovery quantity. This post-hoc test  
174 allowed to evaluate the influence of three other factors on the recovered quantity of  
175 HEV obtained for each sample: (1) the weight of the sample (3 g or 10 g), (2) dilution  
176 of the food sample (ratio 1:5 or 1:10 in buffer elution) and (3) the homogenisation of  
177 the sample (stomacher or FastPrep).

178 Graphs plotting the mean and its standard error for each group illustrate the multiple  
179 comparison procedure. When confidence intervals of means do not overlap, the  
180 difference between two groups of a factor is significant.

181

### 182 **3. Results**

#### 183 **3.1 Quantification of HEV in naturally contaminated figatellu, sausage and liver** 184 **samples according to the elution method used**

185 To compare the efficiency of six elution methods in extracting HEV from food  
186 samples, HEV genomes were quantified from naturally contaminated figatellu, pig  
187 liver sausage and liver. The amounts of HEV genomes recovered from food samples  
188 by using each of the elution method were normally distributed as illustrated by the  
189 symmetrical bell-shaped of quantitative data obtained with the reference method B  
190 (Figure 2). The means and standard deviations of HEV quantities obtained for each  
191 food type according to the elution method used are displayed in Figure 3.

192 HEV genomes were detected in all RNA samples. The quantification of HEV in  
193 sausage, figatellu and liver ranged respectively from 8.79 to 9.70, 6.92 to 7.82 and

194 8.64 to 8.96 log<sub>10</sub> HEV genome per gram whatever the elution method used.  
195 Quantitative data calculated from undiluted and 10-fold diluted RNA extracts were  
196 similar since their ratio ranged from 0.90 to 0.99 regardless the food type and the  
197 elution method used. Thus, there was no relevant inhibition of HEV RNA  
198 amplification.

199 Comparisons between quantitative data obtained by using the reference method B  
200 with those obtained by using other elution methods indicated that the method D  
201 provided the highest quantification for HEV (Figure 3). Indeed, the means of HEV  
202 recovered by using the method D were 7.82 and 9.70 log<sub>10</sub> HEV genome per gram in  
203 Figatellu and pig liver sausage respectively, whilst they were 6.92 and 8.94 log<sub>10</sub>  
204 HEV genome per gram with the method B. In addition, a slightly increase in HEV  
205 quantification could be also observed by using methods F (9.28 log<sub>10</sub> HEV genome  
206 per gram) and E (9.50 log<sub>10</sub> HEV genome per gram) for pig liver sausages. On the  
207 contrary, HEV levels found in liver were similar regardless the elution method since  
208 their ranges were from 8.64 to 8.96 log<sub>10</sub> HEV genome per gram.

209 The standard deviation values were higher for liver (from 0.37 to 0.68 log<sub>10</sub> HEV  
210 genome per gram) than for figatellu (from 0.15 to 0.34 log<sub>10</sub> HEV genome per gram)  
211 regardless the elution method used. The standard deviation values obtained from pig  
212 liver sausage were close to the ones obtained for figatellu (from 0.13 to 0.30 log<sub>10</sub>  
213 HEV genome per gram) except by using the method D (0.68 log<sub>10</sub> HEV genome per  
214 gram) (Figure 3). This result showed that quantitative data of liver samples were the  
215 most widely spread, also illustrated by the flattened peak in Figure 2.

216 As a whole, these results indicated that the elution method influenced the amounts of  
217 HEV genome recovered from figatellu and sausage; and that the quantitative data

218 obtained from liver were the most widely distributed regardless the elution method  
219 used.

220

### 221 **3.2. Assessment of the experimental factors essential to increase HEV** 222 **genomes recovery from figatellu, pig liver sausage**

223 To determine whether elution method has an impact on HEV extraction from food,  
224 statistical analysis was further performed on HEV quantitative data obtained  
225 according to the elution method used. Results of the one-way ANOVA showed that  
226 the elution method was a significant factor for improving the HEV recovery from  
227 figatellu (ANOVA;  $p=0.0011$ ) and from sausage (ANOVA;  $p<0.0001$ ). On the  
228 contrary, none of the elution methods could significantly improve HEV recovery from  
229 liver (ANOVA;  $p=0.5295$ ).

230 A multiple comparison test was further performed to identify the most efficient elution  
231 method in extracting HEV. As shown in Figure 4, the method D provided the highest  
232 HEV recovery from figatellu and pig liver sausage and the methods E and F also  
233 showed a better efficiency in HEV recovery from sausages.

234 In addition, pairwise comparisons of HEV quantities obtained between the reference  
235 method B and others could determine the most efficient experimental factors leading  
236 to a significant improvement in extracting HEV from figatellu and pig liver sausage.

237 To evaluate independently the influence of the type of grinding, the sample weight  
238 and the ratio weight to volume of elution buffer (w/v), HEV quantities obtained by  
239 using the method B were respectively compared to the ones obtained with method A,  
240 method C and method E. The ratio weight to volume of elution buffer was the only  
241 factor leading to a significant increase in HEV recovery from pig liver sausages.

242 The influence of sample weight as an additional factor to the ratio w/v was further  
243 evaluated by comparing HEV quantities obtained using method B with those obtained  
244 with method F. Nevertheless, the increase of sample weight from 3 g (method B) to  
245 10 g (method F) did not lead to a significant increase in HEV quantities recovered  
246 from figatellu. On the contrary, the use of FastPrep homogenizer when elution buffer  
247 was added to figatellu samples with a ratio of 1:5 (method D) instead of 1:10 (method  
248 B) showed to be a significant experimental factor. This result showed that both  
249 experimental parameters are necessary to significantly increase HEV recovery from  
250 figatellu.

251 As a whole, the method D proved to be the most effective for HEV extraction from  
252 figatellu and sausage whereas none of the elution method had impact on HEV  
253 recovery from liver.

254

#### 255 **4. Discussion**

256 The foodborne transmission of HEV is mainly due to consumption of raw or  
257 undercooked liver, meat or sausage from infected animal reservoirs such as pigs or  
258 wild boar (Yugo and Meng, 2013). The detection of HEV genome was reported in  
259 several organs of infected pigs (liver, plasma, bile, hepatic lymph node, etc.) with the  
260 highest viral load reported in liver, *i.e.*  $10^7$  per gram (Leblanc et al., 2010; Son et al.,  
261 2014). In assessing the risk related to the presence of HEV in food, detection  
262 methods were previously developed and allowed highlighting the high prevalence  
263 (*i.e.* up to one third) of HEV in Europe for foodstuffs containing pig liver, (Szabo et al.,  
264 2015; Giannini et al., 2018; Di Bartolo et al., 2015; Moor et al, 2018; Martin-Latil et  
265 al., 2014). Regarding the quantitative data, virus load of up to 5.7 log<sub>10</sub> HEV genome  
266 copies per gram were measured (Moor et al., 2018; Giannini et al., 2018; Martin-Latil

267 et al., 2014). In the framework of a French monitoring programme, the developed  
268 method was efficient for the detection of HEV in figatelli and pig liver sausages as  
269 most of the samples tested had a recovery rate of MNV process control enough  
270 raised to validate analysis. On the contrary, the low recovery rates obtained for MNV  
271 from pig dried salted liver and quenelle samples underlined that the performance of  
272 the method should be further improved (Martin-Latil et al., 2014).

273 In this aim, the present study focuses on the extraction of the virus from food, which  
274 is a critical step because of the internal contamination of pig liver products with HEV.  
275 An improvement in HEV recovery was found for figatellu and sausage samples with  
276 the method D in comparison with the previously published method B (Martin-Latil et  
277 al., 2014). To validate method D according to the EN ISO 16140, further analysis  
278 should be performed by increasing the sampling for every type of food and by taking  
279 into account at least, three levels of viral contamination as previously for method B  
280 (Martin-Latil et al., 2016). Both crucial parameters were the ratio weight to volume of  
281 elution buffer and the type of mechanical cell disruption for figatelli and pig liver  
282 sausages. Nevertheless, the ratio weight to volume of elution buffer 1:5 was sufficient  
283 to significantly increase the recovered quantities of HEV from pig liver sausages. The  
284 use of the FastPrep®-24 homogeniser showed to be an additional significant factor  
285 for releasing HEV from naturally contaminated figatellu samples. Since the grinding  
286 step is important for extracting virus from food of animal origin, the efficiency of  
287 several strategies of mechanical cell disruption was previously described, *e.g.* the  
288 use of vortex mixer or stomacher, which is part of the standard equipment in many  
289 laboratories, or a FastPrep®-24 instrument, which is a more drastic mechanical  
290 homogeniser (Di Bartolo et al., 2015; Szabo et al., 2015; Wilhelm et al., 2014; Berto  
291 et al., 2013; Martin-Latil et al., 2014). A more efficient homogenisation of food

292 samples was found with stomacher and FastPrep®-24 by detecting the released pig  
293 DNA following the homogenisation process (Szabo et al., 2015). Different cycles of  
294 freeze thawing could be also used to disrupt mechanical samples of liver (Serracca et  
295 al., 2015). Nevertheless, the strategies of mechanical cell disruption should be  
296 chosen to keep intact viral particles for further analysis of HEV infectivity once a  
297 suitable cell culture method will be available for routine use.

298 In our study, the weight of sample did not influence the quantity of HEV recovered per  
299 gram for any food matrices showing that an increase of sample weight did not  
300 hamper the efficiency of the grinding step, neither the detection of HEV genomes by  
301 RT-qPCR. Sample sizes of swine liver samples ranging from 250 mg to 10 g were  
302 analysed for the presence of HEV in previous studied (Bouwknegt et al., 2007;  
303 Leblanc et al., 2010; Son et al., 2014; Martin-Latil et al., 2014). In particular, Son et  
304 al. (2014) showed that the detection rate of HEV in swine liver was improved (three  
305 times more detection) by increasing the sample size from 1 g to 10 g when a  
306 concentration step followed HEV extraction. It should be noted that an increase of the  
307 sample size, as an additional step of virus concentration, could lead to an increase in  
308 PCR inhibitors. For this reason, Szabo et al. (2015) analysed 2 g of liver sausage to  
309 compensate for the expected higher amounts of inhibitory substances in liver-  
310 containing matrices. However, no significant evidence of RT-qPCR inhibition was  
311 shown in this work for detecting HEV in any food matrices whatever the method used  
312 in agreement with our previous studies (Martin-Latil et al., 2014 and 2016).

313 The quantitative data obtained from liver were more widely distributed for liver than  
314 for figatellu and pig liver sausage whatever the elution method used as shown by the  
315 standard deviation values. The difference in HEV genomes distributions according to  
316 food type may reflect the actual physical distribution of HEV in a particular food

317 product. The highest variability in amounts of HEV genomes found in liver could  
318 reflect a heterogeneous contamination resulting from a focal infection in swine liver  
319 but further analysis should be performed to confirm this statement. Non-homogenous  
320 contamination of food has been already discussed since HEV could not be detected  
321 in all slices for the same sausage (Di Bartolo et al., 2015). Nevertheless, the level of  
322 HEV contamination was at least 2 log<sub>10</sub> lower than the figatellu and sausage used for  
323 this study and the weight of samples was 250 mg.

324 On the contrary, figatelli and pig liver sausages may be homogeneously  
325 contaminated with HEV since both matrices are already made by mixing meat, fat  
326 and liver together with salt and spices. The physical distribution of the microbial  
327 contamination among batch samples has already been shown to affect the observed  
328 microbial frequency distribution (Jongenburger et al., 2012).

329 To our knowledge, this study was the first to evaluate several methods for elution of  
330 HEV particles from naturally contaminated food and could be extended for analysing  
331 other food types having internal contamination with pathogens. This approach may  
332 improve the risk assessment towards HEV in food virology.

### 333 **Acknowledgements**

334 Samples were collected within the framework of an official national surveillance plan  
335 organized by the French Ministry of Agriculture, Food and Forestry in 2011, according  
336 to EC Regulation 882/2004 and EC Directive 2003/99/EC (2003), EC Regulation  
337 882/2004 (2004). We wish to thank Dr. Nicole Pavio for providing HEV-contaminated  
338 pig faeces.

339

### 340 **REFERENCES**

341

342 Berto, A., Grierson, S., Hakze-van der Honing, R., Martelli, F., Johne, R., Reetz, J.,  
343 Ulrich, R.G., Pavio, N., Van der Poel, W.H., Banks, M., 2013. Hepatitis E virus in pork  
344 liver sausage, France. Emerg Infect. Dis. 19, 264-266.



345  
346 Bouwknecht, M., Lodder-Verschoor, F., van der Poel, W.H., Rutjes, S.A., de Roda  
347 Husman, A.M., 2007. Hepatitis E virus RNA in commercial porcine livers in The  
348 Netherlands. *J. Food Prot.* 70, 2889-2895.

349  
350 Brassard, J., Gagne, M.J., Genereux, M., Cote, C., 2012. Detection of human food-  
351 borne and zoonotic viruses on irrigated, field-grown strawberries. *Appl. Environ.*  
352 *Microbiol.* 78, 3763-3766.

353  
354 Colson, P., Borentain, P., Queyriaux, B., Kaba, M., Moal, V., Gallian, P., Heyries, L.,  
355 Raoult, D., Gerolami, R., 2010. Pig liver sausage as a source of hepatitis E virus  
356 transmission to humans. *J. Infect. Dis.* 202, 825-834.

357  
358 Deest, G., Zehner, L., Nicand, E., Gaudy-Graffin, C., Goudeau, A., Bacq, Y., 2007.  
359 Autochthonous hepatitis E in France and consumption of raw pig meat.  
360 *Gastroenterol. Clin. Biol.* 31, 1095–1097.

361  
362 Di Bartolo, I., Angeloni, G., Ponterio, E., Ostanello, F., Ruggeri, F.M., 2015. Detection  
363 of hepatitis E virus in pork liver sausages. *Int. J. Food Microbiol.* 193, 29-33.

364  
365 Emerson, S.U., Nguyen, H., Graff, J., Stephany, D.A., Brockington, A., a Purcell,  
366 R.H., 2004. In vitro replication of hepatitis E virus (HEV) genomes and of an HEV  
367 replicon expressing green fluorescent protein. *J. Virol.* 78, 4838-4846.

368  
369 Fumian, T. M., Leite, J. P., Marin, V. A., Miagostovich, M. P., 2009. A rapid procedure  
370 for detecting noroviruses from cheese and fresh lettuce. *J. Virol. Methods.* 155, 39-  
371 43.

372  
373 Giannini, P., Jermini, M., Leggeri, L., Nüesch-Inderbilen, M., Stephan, R., 2018.  
374 Detection of hepatitis E virus RNA in raw cured sausages and raw cured sausages  
375 containing pig liver at retail stores in Switzerland. *J Food Prot.* 81, 43-45.

376  
377 Grodzki, M., Schaeffer, J., Piquet, J.C., Le Saux, J.C., Cheve, J., Ollivier, J., Le  
378 Pendu, J., Le Guyader, F.S., 2014. Bioaccumulation efficiency, tissue distribution,  
379 and environmental occurrence of hepatitis E virus in bivalve shellfish from France.  
380 *Appl. Environ. Microbiol.* 80, 4269-4276.

381  
382 ISO 15216-1(2017). Microbiology of Food and Animal Feed–Horizontal Method for  
383 Determination of Hepatitis A Virus and Norovirus in Food using Real-Time RT-  
384 PCRPart1: Method for Quantification International Organization for  
385 Standardization, Geneva.

386  
387 Jongenburger, I., Reij, M.W., Boer, E.P., Zwietering, M.H., Gorris, L.G., 2012.  
388 Modelling homogeneous and heterogeneous microbial contaminations in a powdered  
389 food product. *Int J Food Microbiol.* 157, 35-44.

390  
391 Jothikumar, N., Lowther, J.A., Henshilwood, K., Lees, D.N., Hill, V.R., Vinje, J., 2005.  
392 Rapid and sensitive detection of noroviruses by using TaqMan-based one-step

393 reverse transcription-PCR assays and application to naturally contaminated shellfish  
394 samples. *Appl. Environ. Microbiol.* 71, 1870-1875.  
395  
396 Khuroo, M.S., Khuroo, M.S., Khuroo, N.S., 2016. Transmission of hepatitis E Virus in  
397 developing countries. *Viruses*, 8.  
398  
399 Leblanc, D., Poitras, E., Gagne, M.J., Ward, P., Houde, A., 2010. Hepatitis E virus  
400 load in swine organs and tissues at slaughterhouse determined by real-time RT-PCR.  
401 *Int. J. Food Microbiol.* 139, 206-209.  
402  
403 Martin-Latil, S., Hennechart-Collette, C., Delannoy, S., Guillier, L., Fach, P., Perelle,  
404 S., 2016. Quantification of hepatitis E virus in naturally-contaminated pig liver  
405 products. *Front. Microbiol.* 7, 1183.  
406  
407 Martin-Latil, S., Hennechart-Collette, C., Guillier, L., Perelle, S., 2014. Method for  
408 HEV detection in raw pig liver products and its implementation for naturally  
409 contaminated food. *Int. J. Food Microbiol.* 176, 1-8.  
410  
411 Martin-Latil, S., Hennechart-Collette, C., Guillier, L., Perelle, S., 2012. Duplex RT-  
412 qPCR for the detection of hepatitis E virus in water, using a process control. *Int. J.*  
413 *Food Microbiol.* 157, 167-173.  
414  
415 Masuda, J., Yano, K., Tamada, Y., Takii, Y., Ito, M., Omagari, K., Kohno, S. 2005.,  
416 Acute hepatitis E of a man who consumed wild boar meat prior to the onset of illness  
417 in Nagasaki, Japan. *Hepatology research : the official journal of the Japan Society of*  
418 *Hepatology* 31, 178-183.  
419  
420 Moor, D., Liniger, M., Baumgartner, A., Felleisen, R., 2018. Screening of ready-to-eat  
421 meat products for hepatitis E virus in Switzerland. *Food Environ Virol.*  
422 <https://doi.org/10.1007/s12560-018-9340-x>  
423  
424 Pavio, N., Merbah, T., Thebault, A., 2014. Frequent hepatitis E virus contamination in  
425 food containing raw pork liver, France. *Emerg. Infect. Dis.* 20, 1925-1927.  
426  
427 Renou, C., Gobert, V., Locher, C., Moumen, A., Timbely, O., Savary, J., Roque-  
428 Afonso, A.M., 2014. Prospective study of Hepatitis E Virus infection among pregnant  
429 women in France. *Virol. J.* 11, 68.  
430  
431 Serracca, L., Battistini, R., Rossini, I., Mignone, W., Peletto, S., Boin, C., Pistone, G.,  
432 Ercolini, R., Ercolini, C., 2015. Molecular Investigation on the Presence of Hepatitis E  
433 Virus (HEV) in Wild Game in North-Western Italy. *Food Environ. Virol.* 7, 206-212.  
434  
435 Smith, D.B., Purdy, M.A., Simmonds, P., 2013. Genetic variability and the  
436 classification of hepatitis E virus. *J. Virol.* 87, 4161-4169.  
437  
438 Son, N.R., Seo, D.J., Lee, M.H., Seo, S., Wang, X., Lee, B.H., Lee, J.S., Joo, I.S.,  
439 Hwang, I.G., Choi, C., 2014. Optimization of the elution buffer and concentration  
440 method for detecting hepatitis E virus in swine liver using a nested reverse

441 transcription-polymerase chain reaction and real-time reverse transcription-  
442 polymerase chain reaction. *J. Virol. Methods* 206, 99-104.  
443  
444 Szabo, K., Trojnar, E., Anheyer-Behmenburg, H., Binder, A., Schotte, U., Ellerbroek,  
445 L., Klein, G., Johne, R., 2015. Detection of hepatitis E virus RNA in raw sausages  
446 and liver sausages from retail in Germany using an optimized method. *Int. J. Food*  
447 *Microbiol.* 215, 149-156.  
448  
449 Tamada, Y., Yano, K., Yatsushashi, H., Inoue, O., Mawatari, F., Ishibashi, H., 2004.  
450 Consumption of wild boar linked to cases of hepatitis E. *J. Hepatol.* 40, 869-870.  
451  
452 Tei, S., Kitajima, N., Takahashi, K., Mishiro, S., 2003. Zoonotic transmission of  
453 hepatitis E virus from deer to human beings. *Lancet (London, England)* 362, 371-  
454 373.  
455  
456 Terio, V., Bottaro, M., Pavoni, E., Losio, M.N., Serraino, A., Giacometti, F., Martella,  
457 V., Mottola, A., Di Pinto, A., Tantillo, G., 2017. Occurrence of hepatitis A and E and  
458 norovirus GI and GII in ready-to-eat vegetables in Italy. *Int. J. Food Microbiol.* 249,  
459 61–65.  
460  
461 Teshale, E.H., Grytdal, S.P., Howard, C., Barry, V., Kamili, S., Drobeniuc, J., Hill,  
462 V.R., Okware, S., Hu, D.J., Holmberg, S.D., 2010. Evidence of person-to-person  
463 transmission of hepatitis E virus during a large outbreak in Northern Uganda. *Clin.*  
464 *Infect. Dis.* 50, 1006-1010.  
465  
466 Wilhelm, B., Leblanc, D., Houde, A., Brassard, J., Gagne, M.J., Plante, D., Bellon-  
467 Gagnon, P., Jones, T.H., Muehlhauser, V., Janecko, N., et al., 2014. Survey of  
468 Canadian retail pork chops and pork livers for detection of hepatitis E virus,  
469 norovirus, and rotavirus using real time RT-PCR. *Int. J. Food Microbiol.* 185, 33-40.  
470  
471 Yazaki, Y., Mizuo, H., Takahashi, M., Nishizawa, T., Sasaki, N., Gotanda, Y.,  
472 Okamoto, H., 2003. Sporadic acute or fulminant hepatitis E in Hokkaido, Japan, may  
473 be food-borne, as suggested by the presence of hepatitis E virus in pig liver as food.  
474 *J. Gen. Virol.* 84, 2351-2357.  
475  
476 Yugo, D.M., and Meng, X.J., 2013. Hepatitis E virus: foodborne, waterborne and  
477 zoonotic transmission. *Int. J. Env. Res. Public Health.* 10, 4507-4533.  
478