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Which domestic refrigerator temperatures in Europe? - Focus on shelf-life studies regarding *Listeria* *monocytogenes* (Lm) in ready-to-eat (RTE) foods

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► To cite this version:

Ludivine Bonanno, H el ene Bergis, Nathalie Gnanou-Besse, Adrien Ass er e, Corinne Danan. Which domestic refrigerator temperatures in Europe? - Focus on shelf-life studies regarding *Listeria monocytogenes* (Lm) in ready-to-eat (RTE) foods. *Food Microbiology*, 2024, 123, pp.104595. 10.1016/j.fm.2024.104595 . hal-04633366

HAL Id: hal-04633366

<https://hal.science/hal-04633366v1>

Submitted on 16 Jul 2024

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1 **Which domestic refrigerator temperatures in Europe?**

2 - **Focus on shelf-life studies regarding *Listeria monocytogenes* (*Lm*) in ready-to-eat** 3 **(RTE) foods**

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12

13 **ABBREVIATIONS**

14 *Lm*, *Listeria monocytogenes*; RTEF, Ready-To-Eat Food; FBO, Food Business Operator;
15 TGD, Technical Guidance Document; EURL, European Union Reference Laboratory; NRL,
16 National Reference Laboratory

17

18 **ABSTRACT**

19 *Listeria monocytogenes* (*Lm*) is a pathogenic bacteria able to grow at refrigerated temperatures,
20 widely distributed in the environment. This bacteria is susceptible to contaminate various food
21 products of which refrigerated ready-to-eat foods (RTEF) may pose a risk for public health. In
22 Europe, food business operators (FBOs) shall ensure that foodstuffs comply with the relevant
23 microbiological criteria set out in the Regulation (EC) N 2073/2005. Food safety criteria for
24 *Lm* are defined in RTEF throughout their shelf-life. FBOs should implement studies to
25 demonstrate that the concentration of *Lm* does not exceed 100 CFU/g at the end of the shelf-

26 life, taking into account foreseeable conditions of distributions, storage and use, including the
27 use by consumers. However, this last part of the cold chain for food products is the most difficult
28 to capture and control.

29 For this purpose, the European Union Reference Laboratory for *Lm* (EURL *Lm*) launched an
30 inquiry to its National Reference Laboratory network and reviewed the scientific literature from
31 2002 to 2020. The outcomes were integrated in the technical guidance document of the
32 EURL *Lm* to assess shelf-life of RTEF which resulted in the recommendation to use 10°C as
33 the reference temperature to simulate the reasonably foreseen storage conditions in domestic
34 refrigerators.

35

36 **KEYWORDS**

37 *Listeria monocytogenes*, ready-to-eat foods, shelf-life studies, temperature, domestic
38 refrigerators, food safety

39

40 **1. INTRODUCTION**

41 Listeriosis is one of the most severe foodborne diseases under European Union
42 surveillance in terms of fatality case in high-risk groups of immunocompromised population
43 (EFSA and ECDC, 2023). This disease is mainly caused by *Listeria monocytogenes* (*Lm*), a
44 ubiquitous pathogenic bacterium that can contaminate and grow in a large variety of
45 environments. Due to its tolerance to various physico-chemical conditions and its ability to
46 grow at low temperature, *Lm* is considered as a major microbial hazard for the food safety
47 management from farm to fork, especially in refrigerated ready-to-eat foods (RTEF). In this
48 frame, the European regulation lays down general food safety requirements, according to which
49 food must not be placed on the market if it is unsafe. Especially, specific microbiological criteria

50 for *Lm* are defined in the Regulation (EC) N°2073/2005¹ for different categories of RTEF.
51 Pursuant to Regulation (EC) No 2073/2005 *Lm* is not to be detected in 25g of RTEF intended
52 for infants and for special medical purposes, and in 25g of other RTEF able to support the
53 growth of *Lm* before they have left the immediate control of the producing food business
54 operator. For all other situations, the food safety criterion sets a limit of 100 CFU/g throughout
55 the shelf-life.

56 When the limit is 100 CFU/g, food business operators (FBOs) shall conduct, as
57 necessary, studies to evaluate the growth of *Lm* that may be present in the product during the
58 shelf-life (Reg. (EC) N°2073/2005: article 3 and annex II). These studies should take into
59 account reasonably foreseeable storage conditions susceptible to impact bacterial growth and
60 their fluctuations along the cold chain (from production to consumption). As temperature has a
61 major effect on bacterial growth, challenge tests assessing *Lm* growth potential, and durability
62 studies for chilled RTEF shall mimic realistic time-temperature profiles at all steps of the food
63 chain (at manufacturer, retail and consumer level). Furthermore, storage periods are clearly
64 identified as a factor of tremendous influence on the risk of listeriosis associated with RTEF
65 that support *Lm* growth (FAO and WHO, 2007). Indeed, the relative high and homogenous
66 growth of *Lm* population at refrigeration temperatures has been shown by Rosa Rodrigues de
67 Souza et al. (2023) for a collection of 39 strains. Moreover, quantitative modelling suggests that
68 more than 90% of invasive listeriosis are caused by ingestion of refrigerated RTEF containing
69 *Lm* at concentrations higher than 2,000 CFU/g (EFSA BIOHAZ Panel, 2018).

70 The knowledge of the temperature of domestic fridges leads to assess the growth of *Lm*
71 in potential contaminated foods and consumer exposure. This plays therefore a very important
72 role to assess the risk and contribute to manage food safety.

¹ Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs OJ L 338, 22.12.2005, pp. 1–26.

73 However, this part of the cold chain remains a critical point for harmonized shelf-life
74 studies. At international level, current recommendations of the *Codex Alimentarius* lead to
75 adjust the temperature of household refrigerators so that the temperature of products does not
76 exceed 6°C (preferably 2°C – 4°C) (FAO and WHO, 2007). In Europe, EURL *Lm* Technical
77 Guidance Document (TGD) gives specifications to be considered by laboratories assessing the
78 shelf-life of RTEF related to *Lm* (EURL *Lm*, 2021). The EURL *Lm* TGD is specific for *Lm* and
79 is considered complementary to standard EN ISO 20976-1 for conducting challenge tests
80 studies especially for the growth potential and the maximum growth rate (EN ISO 20976-1,
81 2019). This TGD has also a part dedicated to durability studies. An important point is the use
82 of a time temperature profile to cover each cold chain (at manufacture, retail and consumer
83 level) when performing a challenge test allowing to determine a shelf-life of a product. The
84 TGD recommends that temperatures have to be properly justified and documented by FBOs. It
85 is indicated that “when the FBO has its own data, the use of this information is preferred. In
86 this case, use the 95th percentile of the FBO’s data observation. If no data is available, default
87 temperatures are defined in EURL *Lm* TGD on shelf-life studies. For the last step of the cold
88 chain (consumer storage), a default reference temperature of 12°C has been recommended in
89 the previous version of the EURL *Lm* TGD on shelf-life studies (2008), on the basis of expert
90 opinion. Since then, numerous studies had been carried out in Europe on domestic storage
91 temperatures.

92 Some studies have already reviewed temperature of household refrigerators on a world
93 scale (James et al., 2008; James et al., 2017; Dumitrașcu *et al.*, 2020), but this is the first study
94 to summarize domestic refrigerators temperatures at European level and to assess the impact of
95 these temperatures on shelf-life studies and European application guidelines. Therefore, the
96 goal of this study was to account and gather the recent available data on storage temperatures

97 at consumer level in order to provide FBOs a harmonized approach in setting up shelf-life of
98 prepacked refrigerated products.

99

100 **2. MATERIAL AND METHODS**

101 **2.1. Data collection**

102 To collect the highest number of available data on the temperature storage of foodstuff in
103 household refrigerators, EURL *Lm* used two information channels:

104 - the network of 42 National Reference Laboratories (NRLs) for *Lm*. EURL *Lm*
105 launched an enquiry (Sphinx IQ2 software) in July 2019 among the NRLs *Lm* network
106 in order to identify any surveys that may have been or conducted on the temperature
107 of domestic refrigerator from 2000 to 2020, and to collect data from these surveys. In
108 case of publications of such surveys, the corresponding author was contacted to
109 collect the raw temperature data.

110

111 - in parallel, a review on domestic refrigerator temperatures was performed (PubMed)
112 from the scientific literature published between 2000 to 2020 and referring to the
113 keywords: refrigerator, temperature, food and household. Only scientific publications
114 providing data on the temperature of European household refrigerators were selected.

115

116 **2.2. Temperature distribution and determination of percentiles.**

117 Based on data collected from 10 national surveys and 17 scientific publications, the 75th and
118 95th percentiles of refrigerator temperature distribution were:

- 119 - (1) Directly provided from the survey or the scientific publication (Method 1 – M1),
120 - (2) Calculated from raw temperature data (R software - version 1.4.1106, “*quantile*”
121 function) (Method 2 – M2),

122 - (3) Estimated from graphical temperature distribution reported in the survey report or
123 the publication (Method 3 - M3) or
124 - (4) Estimated from the mean temperature and standard deviation of N measurements
125 using “*rnorm*” and “*matrix*” functions in R (Method 4 - M4) The function “*rnorm*”
126 generates a random simulation of temperatures following a normal distribution. The
127 function “*matrix*” repeats the simulation (1000 iterations were performed in this
128 study). In order to take into account the uncertainty related to the number of refrigerators
129 investigated, the 75th and 95th percentiles were determined by bootstrap approach from
130 each simulation by the function “*rowQuantiles*” and the mean were calculated with the
131 associated 95% confidence intervals (CI).

132

133 **2.3. Statistical analysis**

134 Three kind of statistical analyses were performed in this study. First, a Student’s test was used

135 to evaluate the determination of percentiles (Method M4) in comparison to the other methods.

136 Next, another Student’s test was used to evaluate the difference between refrigerator

137 temperatures measured in air or in food.

138 Finally, countries were grouped according to the Köppen-Geiger climate classification and the

139 weighted average refrigerator temperatures was calculated to take into account the number of

140 refrigerators investigated. A Kruskal-Wallis’s test was used to compare the weighted average

141 refrigerator temperatures according to this classification following by a Dunn’s test to compare

142 Geoclimatic groups by pair.

143

144 **3. RESULTS AND DISCUSSION**

145 **3.1. Data from national surveys**

146 Twenty-nine out of 42 enquired NRLs (69%) replied to the EURL *Lm* questionnaire and among
147 them, seven (24%), have conducted an inquiry in their country. Table 1 presents the general
148 information from each national survey.

149 The number of monitored refrigerators were comprised between 40 and 5 428, mainly
150 investigated in the whole randomly sampled population or by a stratified sampling strategy for
151 two studies (Anses, 2017; Daminelli, 2019). One survey used a selective strategy, targeting
152 elderly people (Denmark survey, 2015). Temperature measurements were performed mostly by
153 a home investigator who installed data loggers inside the refrigerators for a duration varying
154 from 30 min to 7 days. For some studies, the monitoring was performed in the refrigerator (air
155 measurement) at different areas (top, middle and bottom). For one study, loggers were placed
156 between packages of RTEF (Denmark survey, 2015). For two studies, the data loggers were
157 directly put into the food product purchased by consumers, allowing monitoring during several
158 days (Derens et al., 2006; Derens-Bertheau et al., 2015).

159 **Table 1. General information from national surveys**

Country	Year	Scope	Title of the survey	N refrigerators	Target population	Sampling strategy	Data reporting	Monitoring tool	Duration	Air (area of fridge) or Food
Austria	2011	National	Food safety and hygiene in the private household. (Austria survey 2011)	40	Whole population	Random	Interview by phone	TF	?	Air
Belgium	2004	National	Belgian food consumption survey 1 – 2004. (Devriese et al. 2004)	3001	Whole population	Random	Home investigator	?	?	Air
Denmark	2015	District	Investigate the temperature of elderly people refrigerators. (Denmark survey 2015, <i>Unpublished results</i>)	77	Elderly people	Selective	Health Care workers	DL	30 min	Air
France	1999	National	Study of domestic refrigerator temperature and analysis of factors affecting temperature: a French study. (Laguerre et al. 2002)	118	Whole population	Random	Home investigator	DL	7 days	Air (T ; M ; B)
France	2006	National	The cold chain of chilled products under supervision in France. (Derens et al. 2006)	251	Whole population covered French territory	Random	Recorder inside food returning by the consumer	DL	4 days	Food
France	2013	National	Cold chain of chilled food in France. (Derens-Bertheau et al. 2015)	75	Whole population	Random	Recorder inside food returning by the consumer	DL	6 days	Food
France	2014 – 2015	National	Estimate of food consumption & nutritional intake of people living in France. (Anses, 2017)	5428	Whole population	Stratified multi-stage design	Home investigator	TH	30 – 45 min	Air (T ; M ; B)
Ireland	2005	National	Food safety knowledge of consumers and the microbiological and temperature status of their refrigerators. (Kennedy et al., 2005)	100	Whole population	Random	Home investigator	DL	72 h	Air (M)
Italy	2019 – 2020	National	National survey of domestic refrigerators temperatures in Italy (preliminary results) (Daminelli , <i>Unpublished results</i>)	494	Whole population	Stratified sampling plan	Home investigator	DL	?	Air
The Netherlands	2012	National	Food waste. (The Netherland survey 2012, <i>Unpublished results</i>)	326	?	?	Self-reporting via a questionnaire	TH	12 h	Air

160 DL: Data Logger; TH: thermometer; TF: Temperature display on the fridge; T: Top; M: Middle; B: Bottom;?: unknown;

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162 **3.2. Data from scientific literature**

163 The general information from the 17 selected publications is presented in Table 2. These studies were
164 conducted in 11 European countries. The number of monitored refrigerators varied from 30 and 250
165 and were mainly investigated in the whole population. Regarding the sampling strategy, five studies
166 used a random approach. For two studies, the sampling strategy was performed by a selective approach
167 by targeting specific population like students (Galvão et al., 2017) or listeria-sensitive population
168 (elderly, family with children and/or pregnant women (Dumitraşcu et al., 2020)). Two studies used a
169 snowball approach which is used when researchers have difficulties finding participants for their
170 studies (Rossvoll et al., 2014; Ovca et al., 2020). This is a non-probabilistic sampling method where
171 currently enrolled participants help to recruit new participants to form part of the sample. One study
172 was performed by a passive approach based on volunteer families (Azevedo et al., 2005). Finally, the
173 sampling strategy was unknown for five studies.

174 As previously observed, temperature was monitored mainly by data loggers placed inside the
175 refrigerators (air measurement) at different area (top, middle, bottom and door) excepted for two
176 studies where they were placed in water (Garrido et al. 2010) or foods (Marklinder et al., 2004). The
177 duration of the recording varied between 40 min to 14 days. For one study (Garrido et al. 2010), only
178 three measures were performed with a calibrated probe.

179

Table 2. General information from scientific literature

Country	Year	Title of the publication	Target population	Sampling strategy	Monitoring tool	Duration	Air (area of fridge) / Food
Germany; Spain; France; United Kingdom	2002	Cold storage in private households: recommendations and consumer real life behaviour. (Geppert et al. 2010)	?	?	DL	11 days	Air (M)
Sweden	2004	Home storage temperatures and consumer handling of refrigerated foods in Sweden. (Marklinder et al. 2004)	Whole population (Uppsala)	Random	DL	40 min	Food
Portugal	2005	Incidence of <i>Listeria</i> spp. in domestic refrigerators in Portugal. (Azevedo et al. 2005)	North of Portugal	Passive	TH	?	Air
Greece	2005	Modelling the effect of house hold chilled storage condition on the risk distribution of meat product. (Taoukis et al. 2005)	Whole population (Athens metropolitan)	?	DL	7 days	Air
Spain	2007	Survey of Temperature and Consumption Patterns of Fresh-Cut Leafy Green Salads: Risk Factors for Listeriosis. (Carrasco et al. 2007)	Whole population (Cordoba)	Random	DL	24 h	Air
Spain	2010	Temperature distribution in Spanish domestic refrigerators and its effect on <i>Listeria monocytogenes</i> growth in sliced ready-to-eat ham. (Garrido et al. 2010)	Whole population (Pamplona)	?	P	?	Air (T ; M ; B) Water (T ; M ; B)
United Kingdom	2010	Reducing food waste through the chill chain. (George et al. 2010)	Whole population	Representative fridge type	DL	4 days	Air (T ; M ; B)
Greece	2010	Probabilistic Model for <i>Listeria monocytogenes</i> growth during distribution, retail storage, and domestic storage of pasteurized milk. (Koutsoumanis et al. 2010)	?	?	DL	24 h	Air (T ; M ; B ; D)
Italy	2013	Survey conducted in Italy on the consumer refrigeration temperatures and their impact on food safety illustrated with Salmonella. (Roccatò, 2013)	Volunteers population	Random	DL	6 days	Air (T ; B ; D)
Norway	2014	Toxin production and growth of pathogens subjected to temperature fluctuations simulating consumer handling of cold cuts. (Rossvoll et al. 2014)	Specific population (Oslo and Akershus)	Snowball	DL	11 days	Air
Italy	2014	The management of the domestic refrigeration: microbiological status and temperature. (Vegara et al. 2014)	Whole population (Central and North Italy)	?	TH	24 h	Air (M)
United Kingdom	2016	Time-temperature profiling of United Kingdom consumers' domestic refrigerators. (Evans and Redmond, 2016)	Whole population (urban community, South Wales)	Random	P	6 days	Air (M ; D)
Portugal	2017	Thermal performance, usage behaviour and food waste of domestic refrigerators in a university student community: findings towards cities sustainability (Galvão et al. 2017)	Student community University (Beira Interior)	Selective	DL	8 days	Air (M)
Spain	2019	Domestic refrigerator temperatures in Spain: Assessment of its impact on the safety and shelf-life of cooked meat products. (Jofre et al. 2019)	Whole population	Random	DL	24 h	Air (M ; D)
Greece	2019	Field survey on temperature distribution and hygienic status of domestic refrigerators in Lemnos, Greece. (Andritsos et al. 2021)	Island of Lemnos	Random	DL	24 h	Air (T ; B ; D)
Romania; France; Norway; Portugal; United Kingdom	2020	Time-temperature profiles and <i>Listeria monocytogenes</i> presence in refrigerators from households with vulnerable consumers. (Dumitraşcu et al. 2020)	One city per country	Selective	DL	14 days	Air
Slovenia	2020	Temperatures and storage conditions in domestic refrigerators - Slovenian scenario (Ovca et al. 2020)	?	Snowball	DL	7 days	Air (M)

DL: Data Logger; TH: thermometer; P: Calibrated probe; T: Top; M: Middle; B: Bottom; D: Door; ?: Unknown

182 3.3. Combined data and temperature analysis

183 The refrigerator data were collected from 16 European countries: 14 out of the 27 EU member states
184 (MSs) and two non-MSs (Norway and the United Kingdom) (Figure 1). Published storage temperatures
185 at consumer level may present a large scale at European level, depending on multi-criteria factors
186 linked to, the area of the refrigerator where the temperature was registered, individual knowledge of
187 proper management of domestic refrigerator, consumer awareness on their role in food safety, etc. A
188 total 10 national surveys and 17 scientific publications were collected for this study to have a general
189 overview of refrigerator temperature at European level. Most of the studies/surveys targeted the whole
190 population of a defined geographic area. Few of them focused on a specific population such as students,
191 elderly, families with infants and/or pregnant women and young single men. The temperature
192 measurements were mainly carried out using data loggers at different places inside the refrigerator,
193 including the top, middle, bottom and the door or inside a food, mainly RTEF. Measurement using the
194 data logger method allows the true operating conditions of the refrigerator to be represented.

195 However, some limitations can be pointed out. In some surveys/studies the sampling was not randomly
196 performed and the number of refrigerators investigated was lower than 100, which may lead to a bias
197 and not reflect the overall population. For a few studies, the measurement method was performed with
198 a thermometer and did not allow continuous measurements to be taken over a given period of time, as
199 with data loggers, in order to establish a precise mean temperature value. Finally, there was an under-
200 representation of Northern Europe (i.e. Denmark, Estonia, Finland, Latvia and Lithuania). It would
201 have been preferable to have data from a European survey that covered all European countries and use
202 the same methodology to measure the temperature of domestic refrigerators as the method described
203 by Derens-Bertheau et al. 2015.

204

205 In total, from the 27 studies, temperature measures were performed on 9,926 refrigerators. The mean
206 temperature and the percentile (75th and 95th) were determined from each of them (Table 3). The 75th
207 and 95th percentiles were obtained for 25 out of the 27 studies. For one study, no raw data or graphic

208 representation of the data was available to perform the percentile determination (Rossvoll et al. 2014).
209 For 13 of the 26 studies (50%), the 75th and 95th percentiles were calculated using method M2. For the
210 remaining 13 studies, percentiles were estimated using methods M4 (8), M1 (3) and M3 (2). Regarding
211 the eight studies (30%) for which the determination of percentiles was estimated based on a simulation
212 (Method M4) from available data (number of refrigerators, the average of refrigerator temperature and
213 the associated standard deviation), this method is conditioned by a normal distribution assumption of
214 the data (Pouillot et al. 2007). The normality of the data sets was verified with statistical test within
215 three studies: Kennedy et al., 2005 (by Roccato et al., 2017), Taoukis et al., 2005, Carrasco et al., 2007.
216 For three other studies (Koutsoumanis et al., 2010; Roccato, 2013; Evans and Redmond, 2016), it was
217 assumed that the data follow a normal distribution based on the visual appearance of the temperature
218 distribution curves presented in the publications. Finally, for two last studies, this information was
219 unknown (Austria survey, 2011; The Netherland survey, 2012). This approach allowed to take these
220 studies into account, and not reject them (due to the absence of raw data), in order to cover as many
221 European countries as possible, such as Austria, Republic of Ireland and the Netherlands. The
222 robustness of this approach was also assessed by comparing percentiles obtained from studies with M2
223 method (based on raw data). For these studies, percentiles were calculated with M4 method. Results
224 obtained with M2 method were included in the confidence interval obtained from M4 method. The
225 75th percentiles average and the 95th percentiles were not significantly different by the use of the four
226 different methods (p-value = 0.48 and 0.79, respectively).

227

228 The refrigerator temperatures measured either in the air or in food, ranged respectively between 4.1 to
229 8.7°C and 5.7 to 8.0°C. The average of these temperatures from air (6.4°C±1.0°C) and food
230 (6.6°C±0.6°C) were not significantly different (p-value=0.44, Student test). Based on these results, the
231 analysis was conducted combining air and food data. Figure 2 presents a graph of the refrigerator
232 temperature mean (A), the 75th percentile (B) and the 95th percentile (C) per European country analyzed
233 in this study. The refrigerator temperatures in European countries ranging from 4.1 to 8.7°C, with a

234 mean of $6.4^{\circ}\text{C}\pm 0.9^{\circ}\text{C}$ (dotted line in figure 2A). This mean is close to the temperature that products
235 should not exceed according to the Codex guidelines (i.e. 6°C). Moreover, this value is similar to the
236 global mean air temperatures (6.1°C) measured in the 35 worldwide surveys reviewed by James et al.,
237 2017. The 75th percentiles are comprised between 5.0 and 10.4°C , with a mean of $7.9^{\circ}\text{C}\pm 1.1^{\circ}\text{C}$ (dotted
238 line in Figure 2B). The 95th percentiles are comprised between 8.0 and 13.9°C , with a mean of
239 $10.3^{\circ}\text{C}\pm 1.4^{\circ}\text{C}$ (dotted line in Figure 2C).

240 All these results indicated that, variability of temperature depends on the refrigerator age, the internal
241 thermostat that allows temperature adjustment, the frequency and the duration of door opening and the
242 refrigerator's loading rate.

243

244 The 16 European countries were classified according to the Köppen-Geiger climate classification
245 (Beck et al., 2018) (Figure 1). The data used for this classification correspond to the period considered
246 in our study. The aim was to compare the temperature of domestic refrigerators according to
247 geoclimatic zones. Our results showed that the weighted average refrigerator temperatures of the three
248 geoclimatic groups was 6.9°C , 6.3°C and 6.6°C respectively for temperate climate with dry summer
249 (Cs), temperate climate without dry season (Cf) and cold climate without dry season (Df) (Table 4).

250 The Kruskal-Wallis's test showed that there was a significant difference ($p\text{-value} = 0.0311$) in the
251 mean refrigerator temperature mean within the three categories. The Dunn's test showed that the mean
252 refrigerator temperature of the Cf group countries was significantly lower than that of the Cs group
253 countries ($p\text{-value} = 0.0283$). On the other hand, there was no significant difference between the Cf
254 group and the Df group and between the Df group and the Cs group. However, in the case of Df group,
255 the low number of studies and refrigerators investigated could explain the lack of significant results.
256 Moreover, these results only represent between 0.6 to 10.5% of the households in European countries
257 surveyed (Table 4). Thus, it would be interesting to recommend an update of these data according to
258 or on the basis of more representative population data and climate change.



259|

260| **Figure 1. European countries where data on temperature of domestic refrigerators (from**
 261 **national surveys and scientific literature) were collected clustered according the Köppen-Geiger**
 262 **climate classification (described by Beck et al., 2018)**

263 *Legend of figure 1: Dark grey, Cold climate without dry season (Df); Medium grey, Temperate climate without*
 264 *dry season (Cf); Light grey, Temperate climate with dry summer (Cs)*

265 *(Map created from <https://www.mapchart.net/europe.html>)*

266|266

267 **Table 3. Collected data from national surveys and scientific literature and determination of the**
 268 **75th and 95th percentile of refrigerator temperatures**

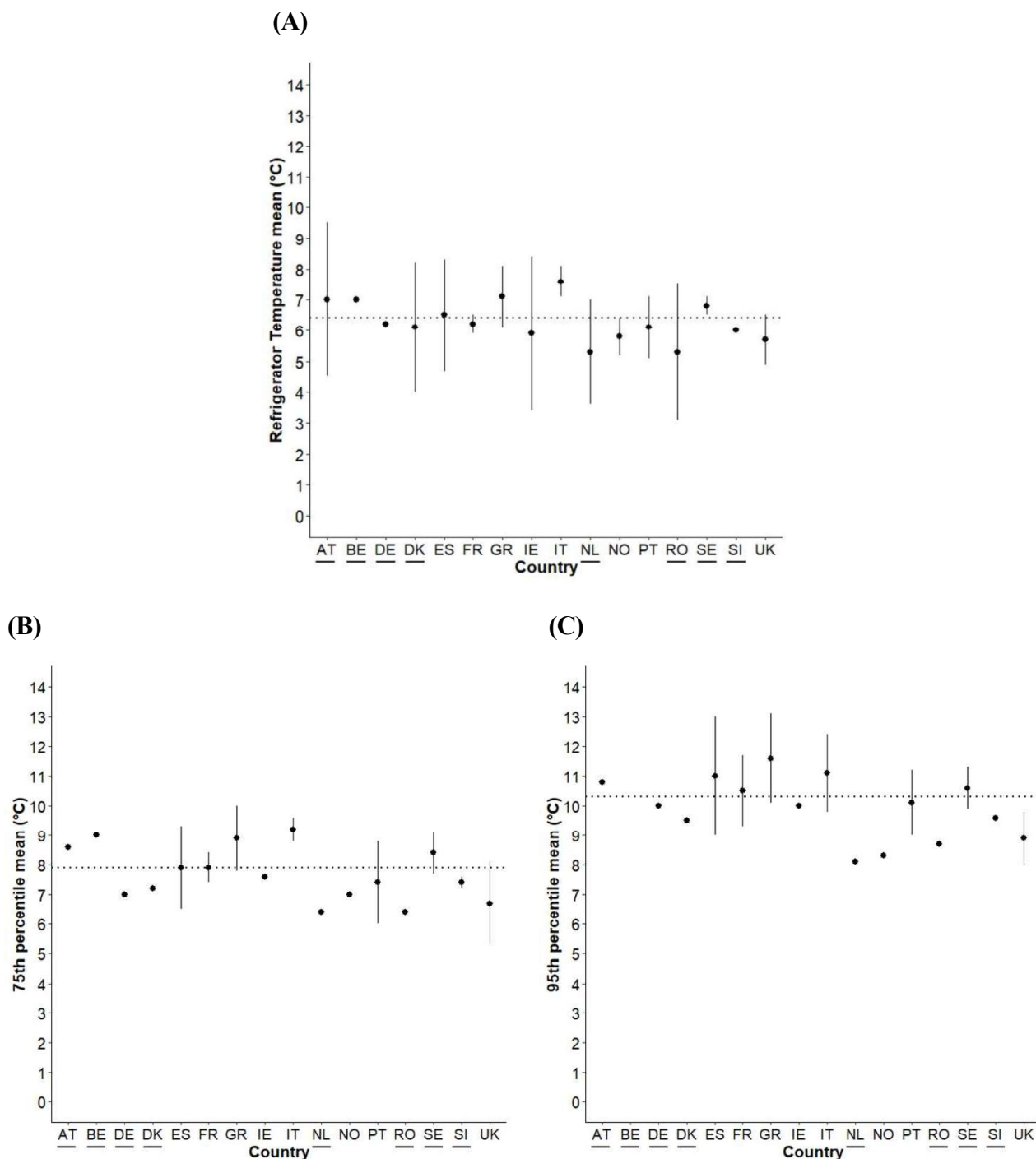
Country	Reference	N refrigerator	Monitoring tool	Recorder position (Air / Food)	T° Mean ± SD (°C)	T° min (°C)	T° max (°C)	75 th percentile (°C)	95 th percentile (°C)	Percentile method
AT	Austria survey 2011	40	TF	Air	7.0 ± 2.5	2.0	13.0	8.6 [7.6, 9.7] ^a	10.8 [9.4, 12.4] ^a	M4
BE	Devriese et al., 2004	3001	?	Air	7.0 (±?)	?	?	9.0	?	M1
DE	Geppert et al., 2010	100	DL	Air	6.2 (±?)	0.0	11.0	7.0	10.0	M3
DK	Denmark survey 2015	77	DL	Air	6.1 ± 2.1	0.0	10.0	7.2	9.5	M2
ES	Carrasco et al., 2007	30	DL	Air	6.6 ± 2.6	?	?	8.3 [7.0, 9.6] ^a	10.5 [8.9, 12.3] ^a	M4
	Garrido et al. 2010	33	P	Air	8.3 ± 2.8	3.9	14.6	9.3	13.5	M2
				Food	8.0 ± 2.7	3.9	14.4	8.9	12.6	M2
	Geppert et al. 2010	100	DL	Air	4.1 (±?)	0.0	10.0	6.0	9.0	M3
Jofre et al. 2019	106	DL	Air	5.4 ± 2.1	0.6	12.7	6.9	9.2	M1	
FR	Anses 2017	3767	TH	Air	5.9 ± 2.9	-3.0	15.0	8.0	11.0	M2
	Derens et al. 2006	251	DL	Food 1	5.7 ± 3.2	-4.8	13.8	7.4	11.1	M2
				Food 2	6.1 ± 2.9	-2.0	12.5	7.9	11.7	M2
				Food 3	6.0 ± 2.2	1.1	10.8	7.5	9.7	M2
	Derens-Bertheau et al., 2015	75	DL	Food	6.3 ± 2.2	1.1	10.7	8.1	9.9	M2
	Dumitrașcu et al., 2020	15	DL	Air	6.4 ± 1.4	4.0	8.3	7.3	8.2	M2
	Geppert et al., 2010	100	DL	Air	6.7 (±?)	1.0	12.0	9.0	12.0	M3
Laguerre et al. 2002	118	DL	Air	6.6 ± 2.2	0.9	11.4	8.2	10.2	M2	
GR	Koutsoumanis et al., 2010	100	DL	Air (Top area)	7.6 ± 3.0	-1.8	14.5	9.6 [8.8, 10.4] ^a	12.4 [11.3, 13.6] ^a	M4
				Air (Middle area)	6.3 ± 2.7	-0.7	13.0	8.1 [7.4, 8.8] ^a	10.6 [9.6, 11.7] ^a	M4
				Air (Bottom area)	6.7 ± 2.3	-2.7	18.1	8.2 [7.6, 8.8] ^a	10.4 [9.5, 11.3] ^a	M4
	Andritsos et al. 2021	70	DL	Air	8.7 ± 3.2	-0.8	17.5	10.4	13.9	M2
Taoukis et al., 2005	250	DL	Air	6.3 ± 2.7	?	?	8.1 [7.7, 8.6] ^a	10.7 [10.0, 11.4] ^a	M4	
IE	Kennedy et al., 2005 ; Rocco et al.2017	100	DL	Air	5.9 ± 2.5	-1.7	11.8	7.6 [6.9, 8.2] ^a	9.9 [8.9, 10.9] ^a	M4
IT	Daminelli 2019	494	DL	Air	7.5 ± 3.1	-1.2	16.4	9.5	12.5	M1
	Rocco 2013	106	DL	Air	7.2 ± 2.5	-3.5	15.2	8.9 [8.2, 9.5] ^a	11.2 [10.3, 12.2] ^a	M4
	Vegara et al. 2014	84	TH	Air	8.1 (±?)	2.5	15.9	?	10.1	M3
NL	The Netherland survey 2012	326	TH	Air	5.3 ± 1.7	?	?	6.4 [6.2, 6.7] ^a	8.1 [7.7, 8.5] ^a	M4
NO	Dumitrașcu et al., 2020	13	DL	Air	5.4 ± 2.1	1.2	8.8	7.0	8.3	M2
	Rossvoll et al., 2014	46	DL	Air	6.2 (±?)	2.9	12.0	?	?	-
PT	Azevedo et al., 2005	86	TH	Air	7.3 ± 2.6	0.9	15.2	9.0	10.9	M2
	Dumitrașcu et al., 2020	15	DL	Air	5.5 ± 1.9	3.2	9.1	6.3	8.9	M2
	Galvão et al., 2017	51	DL	Air	5.5 ± 2.7	-1.8	11.9	6.9	10.5	M2
RO	Dumitrașcu et al., 2020	14	DL	Air	5.3 ± 2.2	1.7	9.5	6.4	8.7	M2
SE	Marklinder et al., 2004	102	DL	Food 1	6.2 ± 2.3	0.8	11.3	7.3	10.1	M2
				Food 2	6.5 ± 2.5	0.2	12.8	7.9	10.6	M2
				Food 3	6.8 ± 2.0	2.4	13.6	8.1	9.9	M2
				Food 4	6.9 ± 2.2	0.6	13.2	8.4	10.4	M2
				Food 5	7.2 ± 2.4	1.1	12.3	9.1	10.4	M2
				Food 6	7.1 ± 2.5	0.2	12.3	8.9	10.8	M2
				Food 7	6.9 ± 2.8	1.8	18.2	9.1	12.1	M2
SI	Ovca et al. 2020	50	DL	Air	5.9 ± 2.2	-0.3	10.7	7.2	9.6	M2
				Food	6.0 ± 2.2	1.0	10.7	7.5	9.6	M2
UK	Evans and Redmond, 2016	43	P	Air	5.8 ± 1.9	1.8	11.4	7.1 [6.3, 7.8] ^a	8.7 [7.7, 9.9] ^a	M4
	Dumitrașcu et al., 2020	13	DL	Air	5.0 ± 2.7	-0.1	9.3	6.2	8.7	M2
	George et al., 2010	50	DL	Air	6.8 ± 2.3	1.5	11.6	8.4	10.2	M2
	Geppert et al. 2010	100	DL	Air	5.2 (±?)	3.0	10.0	5.0	8.0	M3

270 Table 3 legend:

271 DL: Data Logger; TH: thermometer; TF: Temperature display on the fridge? P: Calibrated probe; SD: Standard deviation; ^a: bootstrap

272 95% Confidence interval;?: Unknown

273



274 **Figure 2. Graph of the refrigerator temperature mean (A), 75th percentile mean (B) and 95th**

275 **percentile mean (C) and associated standard deviation per country.**

276 *Legend of Figure 2A: Underlined country, country for which a single study was collected.*

278 **Table 4: Weighted average refrigerator temperatures according to the Köppen-Geiger climate**
 279 **classification of European countries**

Group	Number of studies	Number of refrigerators included in the studies	Weighted average refrigerator temperatures	Estimated number of households*	Proportion of households surveyed
cold climate without dry season (Df)	6	392	6.6°C	132 901 000	0.6%
temperate climate without dry season (Cf)	12	8009	6.3°C	170 590 000	10.5%
temperate climate with dry summer (Cs)	13	1525	6.9°C	127 633 000	2.8%

280 *Legend of Table 4: *Global population number/number of people per household, sources: INSEE 2020*
 281 *(for UK) and 2021 (others countries); Eurostat 2017 (for UK) and 2022 (others countries)*

282

283 3.4. Taking these data into account for shelf-life studies

284 The results of this study were taken into account in order to revise the EURL *Lm* TGD for conducting
 285 shelf-life studies on *Listeria monocytogenes* in ready-to-eat foods (EURL *Lm* 2019). This revision had
 286 been conducted by the EURL *Lm* with a working group of representatives from seven EU NRLs *Lm*
 287 (Belgium, Denmark, Ireland, Italy, Netherland, Portugal and Sweden) and one non-EU member
 288 (United Kingdom).

289 This working group was also consulted in 2018 to revise the section “Storage conditions” of the
 290 EURL *Lm* TGD for conducting shelf-life studies on *Listeria monocytogenes* in ready-to-eat foods
 291 (EURL *Lm*, 2014) in order to refine the temperature at retail level. In this revision, the value of the
 292 temperature at retail level was based on the 95th percentile temperature distribution (EURL *Lm*, 2015)
 293 and defined as consensus in the amendment 1 of version 3 of the EURL *Lm* TGD for conducting shelf-
 294 life studies on *Listeria monocytogenes* in ready-to-eat foods (EURL *Lm*, 2019).

295 To be consistent with the consensus value recommended for temperature at retail level of the EURL *Lm*
 296 TGD v3 amendment 1 (EURL *Lm*, 2019), the working group decided to select the rounded value of
 297 the 95th percentile distribution as value for the temperature at consumer level. Therefore the value of

298 10°C was kept to propose the revision of the Table 4 of the EURL *Lm* TGD version 4 on challenge
299 tests and durability studies for assessing shelf-life of ready-to-eat foods related to
300 *Listeria monocytogenes* (EURL *Lm*, 2021).

301 **4. CONCLUSIONS**

302 For the first time, a study was carried out to collect data on the temperatures of household refrigerators
303 in 16 European countries and to define a more realistic temperature to mimic the storage of RTEF at
304 consumer stage, used in challenge tests and durability studies for shelf-life validation or verification.

305 A temperature of 10°C, representing the 95th percentile of the studied dataset, was taken for the
306 consumer level to revise the fourth version of the EURL *Lm* TGD on challenge tests and durability
307 studies for assessing shelf-life of ready-to-eat foods related to *Listeria monocytogenes* (EURL *Lm*,
308 2021).

309 The choice of a lower temperature for these tests may lead to increase shelf-life evaluations for RTEF,
310 especially for those based on higher temperature at consumer level (e.g. 12°C as mentioned in the
311 previous versions of the EURL *Lm* TDG). As RTEF shelf-life is not limited to the assessment of *Lm*
312 growth, Food Business Operators may be limited by the growth of spoilage organisms and other quality
313 criteria if they decide to increase the shelf-life of their products. This global approach should be
314 included in a comprehensive food safety management system.

315 These results might be also impacted by several factors, e.g. impact of climate change including overall
316 increased temperatures and other climatic conditions at regional level, but also geopolitical situations
317 which put pressure on energy prices, economic crisis associated to lack of financial resources
318 particularly dedicated for keeping the cold chain. Thus, the situation of the status of home and retail
319 temperatures should be regularly revised.

320 Finally this should nevertheless not replace the need of continuous consumer education and awareness
321 raising in a shared responsibility approach. These observations can be taken into account for the
322 determination of the shelf-life in a RTE foods.

323 **ACKNOWLEDGEMENTS**

324 We thank the NRL network for their collaboration and all authors who shared their raw data.

325 We also thank Laurent Guillier, Researcher in quantitative microbiology and risk assessment at

326 ANSES, for his helping regarding the statistical part.

327

328 **FOUNDING**

329 EURL *Listeria monocytogenes* is co-funded by the European Union. Views and opinions expressed

330 are however those of the authors only and do not necessarily reflect those of the European Union or

331 the European Health and Digital Executive Agency (HaDEA). Neither the European Union nor

332 HaDEA can be held responsible for them.

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