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Time-temperature profiles and *Listeria monocytogenes* presence in refrigerators from households with vulnerable consumers

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ABSTRACT

A transdisciplinary observational study, coupled with a web-based survey, was conducted to investigate refrigerated storage of food, in five European countries. The investigated consumer groups in this study were: young families with small children and/or pregnant women, elderly people, persons with an immunodeficient system, and young single men. The refrigerator temperature was monitored for approximately two weeks using a temperature data logger. Variables such as country, income, age of refrigerators, education, living area, refrigerator loading practices had no significant effect ($p > 0.05$) on the overall average fridge temperature, whereas consumers' practices showed a significant influence ($p < 0.05$) on registered temperature values. Compared to temperatures inside the fridges belonging to young families and young single men group, the temperatures inside refrigerators belonging to elderly was in the temperature danger zone (5–63 °C). The lowest temperatures were recorded in UK consumers' refrigerators, whereas the highest were in French households. Presence of *Listeria monocytogenes* was confirmed in three refrigerators out of 53 sampled (two in Romania and one in Portugal). The most vulnerable category to food safety risks is represented by elderly persons with low education, unaware of safe refrigeration practices and the actual temperature their fridges are running.

1. Introduction

Storage temperature has a significant influence on food quality and safety, especially for foods that must be kept refrigerated or frozen. EFSA, in Europe, and international organizations responsible for people's health, such as the World Health Organization, advise that foods should be refrigerated below 5 °C and frozen at −18 °C (EFSA, 2018). The most critical part of the cold chain is the cold food storage at domestic level, as demonstrated by several studies (James, Onarinde, & James, 2017; Jofré, Latorre-Moratalla, Garriga, & Bover-Cid, 2019). In recent years, the role of inadequate control of food temperature on the number of food poisoning incidents has been highlighted (James, Evans, & James, 2008). Nowadays, the cold food chain is inconceivable without domestic refrigerators (James Onarinde, & James, 2017). Notwithstanding, temperature abuse might happen along the entire food chain (Brown, Ryser, Gorman, Steinmaus, & Vorst, 2015), including households. By storing food properly, consumers are the final line of defense in preventing food spoilage and ensuring food safety (Derens-Bertheau Osswald, Laguerre, & Alvarez, 2014).

In addition, storage temperatures can vary with geographic location (Marklinder, Lindblad, Eriksson, Finnson, & Lindqvist, 2004). The overall variability of temperature in European domestic refrigerators as reported by Rocatto, Uyttendaele, & Membré, (2017) ranged between 7.0 ± 2.7 °C for Southern and 6.1 ± 2.8 °C for Northern countries.

Abbreviations: ELD, elderly people; YF, families with infants and/or pregnant women; YSM, young single men; IDP, immunodeficient and diabetic persons

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While many surveys have been conducted on domestic storage under refrigeration in specific countries (James et al., 2008; James et al., 2017) and in most cases domestic refrigerators were reported to work above 6 °C, few studies have focused on the refrigerated food storage practices of vulnerable consumer groups, and even fewer were conducted simultaneously in several countries, using a comparative methodology. Terpstra, Steenbekkers, De Maertelaere, and Nijhuis (2005) monitored temperatures in the refrigerators of young families with small children and elderly people in the Netherlands, and demonstrated that elderlies have their fridges operating above the recommended temperature for refrigeration (i.e. < 5 °C). The refrigerator temperature of American young adults aged between 18 and 26 years was recorded by Byrd-Bredbemmer, Maurer, Wheatley, Cottone, & Clancy (2007), the authors finding a mean value of 6.1 ± 3.6 °C, with a minimum value of 0 °C, and a maximum value of 16 °C. While food may spend an important part of its shelf life in a domestic refrigerator, the variation of the temperature could favor psychotropic pathogen growth, *Listeria monocytogenes* being frequently reported to affect vulnerable consumers (EFSA, 2018).

Immunodeficient consumers, such as young children, pregnant women and elderly people are more susceptible to foodborne illness than other consumers; however, vulnerability differs greatly between these groups. The elderly are more exposed to foodborne diseases than healthy adults as result of age-associated decreased immunity, gastrointestinal tract changes, antibiotic usage, malnutrition, and sedentary lifestyles (Evans & Redmond, 2015; Lund, 2015). The World Health Organization reported a 2.6 times higher susceptibility of developing a serious illness in the elderly compared with the healthy general population, in the last decade (Evans & Redmond, 2018; 2015). Also, listeriosis affected about 2200 people in 2015, the proportion of cases in the over 64 age group being 64% (EFSA, 2016). Pregnant women are considered 17 times more likely to contract listeriosis than the healthy general population (Feng & Bruhn, 2016). Then, persons with diabetes and immunodeficient people are 25 times more likely to suffer from listeriosis (Feng & Bruhn, 2016). Although not vulnerable, an interesting category of consumers is represented by young single men (< 30 years old). They are considered high risk-takers as they are more prone to disregard food safety practices at home compared with the abovementioned categories (Byrd-Bredbenner, Maurer, Wheatley, Cottone, & Clancy, 2007). Moreover, food handling behaviour of young adults becomes important as they might be involved in the future in taking care of their household members vulnerable to food poisoning. Furthermore, consumers hold specific perceptions of vulnerability, risk and control in relation to their own food safety practices, perceptions that differ according to age, gender, ethnicity, and education (Evans & Redmond, 2019; Redmond & Griffith, 2004).

The aim of this study was to collect information on refrigeration temperatures, occurrence of *L. monocytogenes* and storage of refrigerated foods from different households in five European countries (France, Norway, Portugal, Romania and UK) and evaluate the differences between consumer knowledge and practices considering the high-risk population. Temperature monitoring with data loggers, placed in fridges for a maximum of two weeks, provided solid ground to compare values. A questionnaire evaluated the knowledge and perceptions of consumers regarding refrigeration temperature. This study is part of a larger research project (safeconsume.eu) that aims to explore consumers' food handling practices from "retail to fork", and to find ways to reduce the risk of foodborne illnesses among the European consumers.

2. Materials and methods

2.1. Recruitment

Fifteen households from five countries (Norway, France, Portugal, UK and Romania) were recruited to participate in a transdisciplinary fieldwork, leading to a total of 75 households visited. Based on a call for tender, the recruitment of volunteers from the general public for data collection was subcontracted to a professional service provider (Norstat Norge AS, Oslo, Norway). In each country, the recruitment of participants was performed considering the maximum variation in one area related to vulnerability, education, income, living area. In Portugal, the city of Porto and its Greater Metropolitan Area was chosen, in France the study was conducted in Anger (Maine et Loire), in UK, the visits have been paid in medium sized households from the Midlands, in Romania, Galati county was chosen, whereas in Norway the study area stretched to rural and urban areas surrounding Oslo. Three group types were considered: elderly (ELD; > 65 years of age), families with infants and/or pregnant women (YF), and young single men (YSM, 20–35 years old). All the volunteers were informed about the aim of the research and all the data were collected with consent.

2.2. Time-temperature data collection

The time-temperature profiling was conducted from February to June 2018, in the consumers' domestic kitchens over a period of up to 14 days. Data loggers (Romania: RC5-USB, Elitech, UK; France: ThermoBouton Proges-Plus, Willems, France; Portugal: KOOLTRAK™ Kiedrich, Germany; UK and Norway: EL-USB-2-LCD, Lascar electronics Ltd, Salisbury, UK) were placed in refrigerators, in the zone where the consumers stored highly risky foods such as ready-to-eat (RTE) foods. The data loggers with resolution of 0.1–0.5 °C operated in the range of −30 °C–70 °C (France), −40 °C–85 °C (Romania, Portugal), and −10 °C–40 °C (UK, Norway) and performed measurements with a frequency ranging from 1 min (Norway, UK), to 5 min (Portugal and Romania) and to 1 h (France). A particular situation was encountered in Romania where, in three rural households, the temperature was monitored in a room used by the elderlies to store food (such as raw meat and RTE), as the fridge was switched off in winter season to save energy.

2.3. Detection of Listeria monocytogenes

A total of 53 surfaces were swabbed from the fridges in four countries (15 samples per country in France, Romania and Portugal, and 8 samples in Norway) using SodiBox swab fabrics (320 × 175 mm) (Raisio Diagnostic, Nieuwerkerk aan den IJssel, the Netherlands) premoistened with Ringer solution. Samples were taken from the shelf where consumers stored RTE foods, and from the vegetable cabinet/box (the area analyzed was max. 400 cm^2). After sampling, the cloths were placed in plastic bags and transported to the laboratory in insulated cold boxes (1–4 °C). Until analysis, the samples were kept under refrigeration (less than 24 h). Detection of *Listeria* spp. was performed according to the official method EN ISO 11290-1:1996 in Romania, Norway and France and according to ISO 11290-1:2017 in Portugal. In Romania, tests based on latex agglutination (Oxoid, Wade Road, Basingstoke, Hampshire, UK) were used for the confirmation of *Listeria monocytogenes*, whereas in Portugal confirmation was made based on Gram staining, catalase test, β hemolysis in blood agar, sugar fermentation (xylose, rhamnose, and mannitol) and CAMP test.

2.4. Data analysis of time-temperature profile

Profiled time-temperature data were analyzed using Microsoft Excel 2018. Statistical analysis was conducted using Minitab 19 (Minitab LLC, State College, Pennsylvania, USA) calculating descriptive statistical parameters. Chi-square test was used to compare frequencies among group categories, refrigerator temperatures, refrigerator age and refrigerator loading.

2.5. Questionnaire design and data collection

The SafeConsume Household Survey, conducted between December 2018 and April 2019 resulted in a comprehensive database from which data for five EEA countries (France, UK, Portugal, Romania and Norway) were selected (N = 5009). Sampling was based on a stratified random design, with the education level of the target respondent as stratum variable. Two questions related to consumers' knowledge and perceptions on the fridge temperature were analyzed in this study. The internal reliability of the selected items was tested using Cronbach's alpha and the value of 0.72 indicated good internal consistency. Respondents had the main or shared responsibility for food shopping in households with: ELD (n = 1287), pregnant women (n = 318), YSM below 30 years old (n = 118) and immunodeficient and diabetic persons (IDP) (n = 946). The data were analyzed with Crosstabs' statistics considering education level as layer. Statistical analysis was conducted with SPSS Statistics 20 (IBM Software Group, Chicago, IL).

3. Results and discussion

3.1. Demographic data

Table 1 presents the participants in the field research and their households. The investigated population consisted of 30% YSM households, 35% YF, and 35% ELD, 65% being from urban areas, and 50% having tertiary education and medium income.

3.2. Temperature inside refrigerators

Refrigerators form an important link in the cold chain, and represent a significant vector for domestic foodborne illnesses (Hassan, Dimassi, & El Amin, 2015). In Table 2, the temperatures recorded inside the fridges are presented. An average refrigerator temperature value of 6.3 °C was calculated out of the mean values recorded for the participants from France, regardless of household type. The results were similar to what was found in other studies. Lagendjk, Assere, Derens, & Carpentier, (2008) indicated that in one out of four French households, the average temperature of domestic refrigerators was above 8 °C and only 11% of refrigerators were working at ≤ 4 °C, whereas Geppert (2011, p. 146) indicated a mean recorded temperature value of 6.7 °C. In another study conducted in France, the authors monitored the temperature in 119 domestic refrigerators and reported an average value of 6.6 °C, minimum 0.9 °C and maximum 11.4 °C (Laguerre, Derens, & Palagos, 2002), whereas in the survey conducted by ANSES (2017) with 5428 French households, 51% of fridges had a temperature between 5 °C and 8 °C.

Apart from France, in all the other countries, the highest median temperatures were recorded in ELD households, whereas the lowest values were recorded in YF households, where the median ranged between 3 °C and 5 °C. In UK and Portugal, the median of average temperatures in ELD refrigerators was 6.2 °C and 6.4 °C, respectively, whereas in Norway and Romania, the calculated median was 7.5 °C. Although the median values were pretty similar in the refrigerators of ELD from Romania and Norway, based on the third quartile it can be observed that 75% of the ELDs from Romania have refrigerator temperatures of less than 9.4 °C, whereas in Norway, the third quartile is 8.3 °C, indicating that the ELDs from Romania could be more exposed to food safety risks. As shown by other findings (James et al., 2017), it is not uncommon to find refrigerators from households working above 6 °C. In a study conducted by Terpstra et al., 2005) in the Netherlands with three household types (adults, families with children under four years old, and elderlies), most of the elderlies had their fridges working above 7 °C. A study conducted in UK (Evans & Redmond, 2015) found that 50% of the food stored in the central compartment, and 85% of the food stored in the door, was stored at refrigerator temperatures of > 5 °C in elderly households.

In Portugal, for YSM and YF households, the median temperature was similar (5 °C), whereas in Norway and Romania, small differences (but not significant ones; $p > 0.05$) were noticed. A comparison between household types shows that in four out of five countries, the smallest spread of the data values was registered for the YF group, demonstrating a more homogenous cooling environment and thus a better capacity to prevent the risk of temperature abuse. The same comparison between household types, regardless of the country, shows that the median refrigerator temperature of the ELD group is significantly higher ($p < 0.01$) than for the YF and YSM groups and this makes the elderly the most exposed category to food risk. Despite considering YSM group as high risk-takers, the participants included in this study demonstrated carefulness in keeping their fridges cool, although the investigators could not determine if the reason behind this was a concern about food safety or preference for not having warm beer.

An overall comparison between countries reveals that regardless of household type, the lowest average temperature was monitored in the fridges of UK households, where the median varied from 3 °C (YF) to 6.2 °C (ELD). The average temperature reported so far in UK refrigerators ranged between 4.4 °C and 5.2 °C (Evans, Foster, & Brown, 2014; Geppert, 2011, p. 146), while the minimum and the maximum mean were −0.6 °C and 10.4 °C (Evans et al., 2014). The results reported for the UK in our study are thus in close agreement with those reported by Evans et al. (2014).

Table 1
Description of the households (n = 75) participating in the study.

Household description		Country					Total no. (%)
		France	UK	Portugal	Romania	Norway	
Group category	YSM	5	5	3	5	5	23 (30)
	YF	5	5	6	5	5	26 (35)
	ELD	5	5	6	5	5	26 (35)
Living area	Urban	7	13	11	9	9	49 (65)
	Rural	8	2	4	6	6	26 (35)
Education	Primary	5	3	5	5	0	18 (24)
	Secondary	7	3	2	4	3	19 (25)
	Tertiary	3	8	8	6	12	37 (49)
	ns	0	1	0	0	0	1 (1)
Income[a]	Low	3	4	3	5	3	18 (24)
	Medium	9	9	10	6	6	40 (53)
	High	3	2	2	3	4	14 (19)
	ns	0	0	0	1	2	3 (4)

ns-not specified.

[a] France - low: < 1100 €; medium: 1100–2500 €; high: > 2500€; UK - low: < 1200 €; medium: 1200–2500 €; high: > 2500 €; Portugal - low: < 750 €; medium: 750–2000 €; high: > 2000 €; Romania - low: < 350 €; medium: 350–750 €; high: > 750 €; Norway - low: < 2000 €; medium: 2000–3200 €; high: > 3200 €

Table 2
Temperatures (°C) measured inside fridges in different countries and household types.

Household type	Parameter	Country					Overall average
		France	UK	Portugal	Romania	Norway	
YSM	Median	6.3	4.5	5	5	4.8	5.1
	Q1	5.4	3.6	–	3.8	4	4.2
	Q3	7.2	5.3	–	6.3	5.8	6.2
	min	3.7	3.4	4.1	3.1	1.2	3.1
	max	8.3	8.2	4.9	8.3	8	7.5
YF	Median	6.3	3	5	4.8	4.5	4.7
	Q1	5.6	2	–	2.9	4	3.6
	Q3	6.9	3.7	–	6.1	5.5	5.6
	min	4.4	1.1	3.2	1.8	3.6	2.8
	max	7.5	4.7	8	8.2	5.5	6.8
ELD	Median	6.3	6.2	6.4	7.4	7.6	6.8
	Q1	5.5	5.8	–	5	6	5.6
	Q3	7	7.4	–	9.4	8.3	8.0
	min	4.8	4.5	3.8	3.5	3.1	3.9
	max	8.2	9.2	9.1	12.3	8.8	9.5
% between	< 4 °C	6.7	25	20	26.7	21.4	20
	4–6 °C	40	41.7	53.3	40	42.9	43.6
	> 6 °C	53.3	33.3	26.7	33.3	35.7	36.4
Overall average temperature		6.3	4.6	5.5	5.7	5.6	

Q1-the median of the lower half of the data set; Q3-the median of the upper half of the data set.

Based on Table 2, it can be seen that 20% of the refrigerators were operating at temperatures lower than 4 °C, 43.6% were working between 4 and 6 °C and 36.4% over 6 °C. The lowest percentage of households where refrigerator temperature was found above 6 °C was in Portugal (26.7%) and the highest in France (53.3%). In other studies, conducted in the UK and France, about 70% of the refrigerators were running at temperatures higher than 5 °C (ANSES, 2017; James & Evans, 1992), whereas in Portugal, 70% were running at temperatures above 6 °C (Azevedo et al., 2005).

3.3. Refrigerators time profile operating at temperatures above 6 °C

Time-temperature profile of refrigerators is a good food safety indicator as it shows the real fluctuations of the recorded temperatures and gives a better understanding of the food safety risks related to consumer practices. Few studies have investigated the time-temperature profile of domestic refrigerators. For example, Evans and Redmond (2016) showed that no refrigerator from British households operated at ≤ 5 °C for 6.5 days of study, while in 91% of the duration, the mean temperature exceeded 5 °C. Table 3 shows the percentages of time when domestic kitchen refrigerators operated at temperatures higher than 6 °C. In more than 75% of the duration of the profiling study, about half of the French households and a third of Norwegian households had their refrigerators operating above 6 °C. EFSA recommends refrigeration temperatures below 5 °C, similar to Food Standard Agency in the UK (EFSA, 2018), while in Norway, the maximum recommended temperature is 4 °C (Røssvoll, Jacobsen, Ueland, Einar Granum, & Langsrud, 2010). In 4 out of 15 UK households, refrigerators recorded temperatures above 6 °C for less than or equal to 1% of the total time. In 40% of the Romanian households, up to 25% of the monitored storage time temperature was above 5 °C. The duration of temperature above the threshold value in households is worrisome considering that *L. monocytogenes*, but also some other pathogens present in low number in RTE foods, could overgrow, if the opportunity occurs.

As indicated previously, some families belonging to the Romanian ELD group living in rural area switch off their refrigerators during winter, and use the coldest room of the house to store perishable foods, such as raw meat or RTE. Fig. 1 illustrates an example on how time-temperature variation occurs when using a cool room, rather than a refrigerator, for storing food. Although the median temperature value was 3.7 °C, from Fig. 1 can be seen that, due to varying outdoor temperatures, for about half of the recorded time (168 h), the actual temperature was above 6 °C. These data highlight the risk to which those who embrace such a practice are exposed. Moreover, 168 h of temperature abuse out of the two weeks storage time, which could be assimilated with the average time of storing foods in the fridges at home, would allow, in the worst case scenario, the substantial growth of *L. monocytogenes,* as demonstrated by recent challenge studies made for refrigerated storage at the retailers (Ceuppens, Van Boxstael, Westyn, Devlieghere, & Uyttendaele, 2016). Even if the reported growth rate at 6 °C is low, an increase by a factor of 100 in certain dairy or meat matrices could endanger vulnerable groups.

3.4. Age of refrigerators

Differences related to the age of refrigerators exist between countries and household types (Table 4). In the recruitment criteria of consumers from Norway and France, having an old refrigerator was a specific requirement. However, as this requirement was not shared by the other countries, not all the selected participants had old refrigerators and we can therefore not consider results based on this criterion. In Romania, in all ELD's households, the refrigerator had an average age of above ten years. In Norway, three out of five ELD households had the refrigerator for more than ten years, whereas in Portugal only in one ELD household was the refrigerator less than five years old. In case of YF households, regardless of country type, the highest percentage was calculated for fridges aged less than five years. In Norway and Portugal, in most of the YSM households, the refrigerator age was between 6 and 10 years, whereas in Romania, 3 out of 5 fridges in these households were less than five years old. Overall, 30% of the total number of households had a refrigerator with an age of less or equal to 5 years, 19% between 6 and 10 years, and 21% over 10 years, while 30% have not been reported.

Other studies carried across Europe revealed that in Serbian households, 45% of refrigerators were up to 5-years-old, 36% were up to 10 years old and 19% over 10 years old (Janjic et al., 2016), and in France, up to 66% of households had a refrigerator older than five years (Laguerre et al., 2002; Marklinder et al., 2004). While some surveys reported that age has a significant influence on refrigerator temperature (Janjic et al., 2016), in our study there was no significant correlation between the recorded temperature and refrigerators' age ($p > 0.05$). Our results are in agreement with the study of Hassan et al. (2015).

Table 3
Time profile of refrigerators operating at temperatures higher than 6 °C.

Household type	% of time operating at temperatures higher than 6 °C	Number of refrigerators exceeding recommended temperature for indicated % of time					Total no.(%)
		France	UK	Portugal	Romania	Norway	
YSM	≤1	0	2	1	0	1	4 (5)
	2–25	1	1	1	3	1	7 (9)
	26–50	1	0	1	1	1	4 (5)
	51–75	1	1	0	1	0	3 (4)
	> 75	2	1	0	0	1	4 (5)
	ns	0	0	0	0	1	1(1)
YF	≤1	0	2	1	1	1	5 (7)
	2–25	2	1	4	2	3	12 (17)
	26–50	0	0	0	1	1	2 (3)
	51–75	0	0	0	0	0	0
	> 75	3	0	1	1	0	5 (7)
	ns	0	2	0	0	0	2(3)
ELD	≤1	0	0	1	0	0	1(1)
	2–25	2	2	2	1	0	7 (9)
	26–50	0	1	0	2	0	3 (4)
	51–75	1	0	0	1	0	2 (3)
	> 75	2	0	3	1	4	10 (13)
	ns	0	2	0	0	1	3 (4)
Total		15	15	15	15	15	75

ns-not specified.

In addition, Table 4 shows that most of the participants, regardless of country or consumer group, had fridges that do not have a temperature display. Moreover, many consumers were not sure on how to set the temperature in their fridges. Some indicated they used as reference the sensation of coldness after touching a beverage container to monitor temperature, others thought that the 1 to 5 scale thermostat indicator signaled temperatures, and they thus adjusted the gage to 1, which in fact was the warmest fridge setting. It is well known that today's refrigerators have lots of unique options and features, the following being related to food safety: (1) Inner surfaces coated with silver ions attempting to control the transfer of microorganisms to food, however, the effectiveness of such coating should be further investigated (Kampmann et al., 2008); (2) Temperature displays on doors allowing consumers to monitor the temperature inside the fridge without opening its door (actual temperature) and to set the temperature to specific values (set temperature); (3) Refrigerator temperature alarm announcing when the door is opened or when the temperature inside the fridge is above the set temperature; (4) Compartments with small icons representing specific food or the coldest zone for helping consumers to identify the best place to keep food and to avoid cross contamination. These represent some reasons that are important from the food safety perspective during storage of food at low temperatures and entitle us to support the idea of having new fridges in our households. In fact, the probability of society evolution towards a world controlled by the Internet of all things would not only make our refrigerators smarter and able to let us know when certain items are missing, but also could warn consumers when temperatures are above the threshold value.

3.5. Number of refrigerators-freezers

The most common type of refrigerator observed in our study was a combined refrigerator-freezer (Table 5). Excepting Portugal, where every household involved in the study had just one, a comparison between countries reveals that the number of combined refrigerator-freezer devices is dependent on household type. For example, in

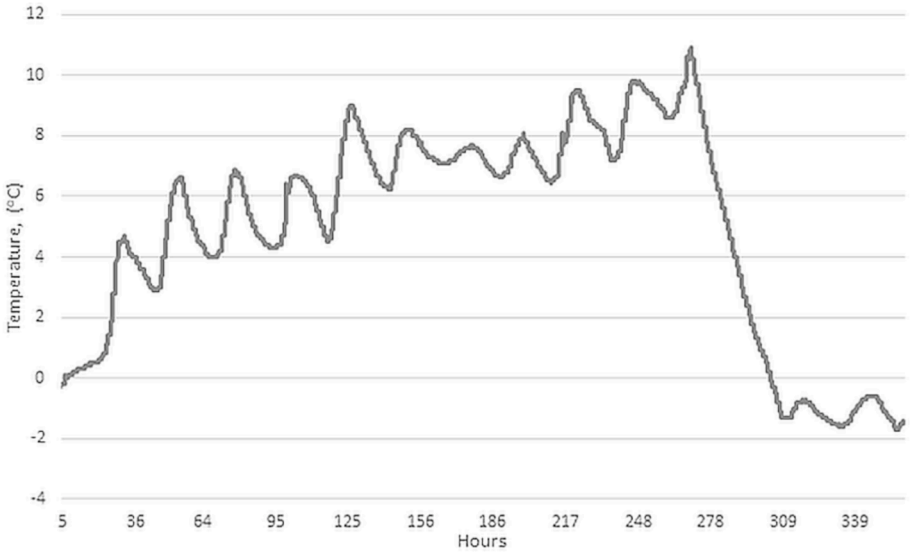

Fig. 1. Time-temperature profile of a room used as refrigerator during winter season.

Table 4
Refrigerator characteristics: age and temperature display.

Household type	Parameter	Country					Total no.(%)
		France	UK	Portugal	Romania	Norway	
Age of refrigerators							
YSM	≤5	2	1	1	3	–	7(9)
	6–10	–	–	2	–	3	5(7)
	> 10	1	–	–	2	–	3(4)
	ns	2	4	–	–	2	8(11)
YF	≤5	2	–	4	3	2	11(14)
	6–10	1	–	2	2	1	6(8)
	> 10	–	1	–	–	–	1(1)
	ns	2	4	–	–	2	8(11)
ELD	≤5	2	–	1	–	2	5(7)
	6–10	1	–	2	–	–	3(4)
	> 10	2	–	2	5	3	12(16)
	ns	–	5	1	–	–	6(8)
Total		15	15	15	15	15	75(100)
Temperature display							
YSM	Yes	0	1	0	2	0	3(4)
	No	5	2	3	3	5	18(24)
	ns	–	2	–	–	–	2(3)
YF	Yes	2	1	1	2	3	9(12)
	No	3	1	5	3	2	14(18)
	ns	–	3	–	–	–	3(4)
ELD	Yes	2	1	1	0	2	6(8)
	No	3	1	5	5	3	17(23)
	ns	–	3	–	–	–	3(4)
Total		15	15	15	15	15	75(100)

Table 5
Numbers of refrigerators and freezers per household.

Household type		Country					Total no.(%)
		France	UK	Portugal	Romania	Norway	
YSM	1[a]	2	3	3	5	5	18(24)
	2	2	2	0	0	0	4(5)
	> 2	1	0	0	0	0	1(1)
YF	1[a]	3	3	6	2	2	16(21)
	2	2	1	0	2	3	8(11)
	> 2	0	0	0	1	0	1(1)
	ns	0	1	0	0	0	1(1)
ELD	1[a]	2	2	6	3	1	14(19)
	2	2	0	0	1	2	5(7)
	> 2	1	2	0	1	2	6(8)
	ns	0	1	0	0	0	1(1)
Total		15	15	15	15	15	75(100)

[a] Combine refrigerator/freezer; ns - not specified.

Norway and Romania, all participants from YSM group had one combined refrigerator-freezer in their households, whereas, in France and UK, two out of five participants had one combined refrigerator-freezer and an extra freezer.

In France and UK, most of the households of YF group had one combined refrigerator-freezer, whereas in Romania and Norway, 3 out of 5 households had an extra freezer or refrigerator. About 15% of ELD households had more than one refrigerator; a percentage that is higher than for the YF and YSM groups, amongst which only 12% and 6% respectively had more than one refrigerator or freezer. Having an extra-refrigerator in the household does not necessarily mean a safer cold chain, as it could involve storing food for a longer time, which in turn could results in problems with the appliances, and higher exposure to risk of pathogens growth.

3.6. Loading practices

The refrigerators loading capacity was estimated based on the occupied volume of the items inside fridge. The fridge was considered full and over packed if more than 75% of fridge volume was occupied; half full if around 50% of the fridge volume was occupied and quite empty if less than 25% of the fridge volume was occupied. Most of the elderly from Norway, Portugal and France had their fridges almost full, whereas in the UK, all kept their fridges half full (Table 6). On the other hand, Romanian ELD kept their fridges half full or quite empty. In winter times, in rural areas, this situation can be explained by storing perishable food outside fridge in the coolest room of the house. A comparison between countries, regardless of household type reveals that in Romania 11 out of 15 investigated household had the fridge half full or quite empty, whereas in the other countries the refrigerator was in most cases full and over packed.

Overall, in more than half of the investigated households, the refrigerators were full and over packed and a third of them were half full. Refrigerators that are packed too tightly with food restrict the cool air from circulating and refrigeration temperature cannot be achieved. Also, the tight packing could increase food-to-food cross-contamination risk (Byrd-Bredbenner et al., 2007). The warmer spots from the fridge could favor the growth of *L. monocytogenes*. In our study, refrigerator loading could not be correlated with recorded temperatures and these findings are in agreement with other studies (Janjic et al., 2016). On the other hand, cold food already stored in the refrigerator contributes to refrigerator temperature stability, whereas an empty or partly empty fridge might lead to larger temperature variations. In addition, the temperature of the food that is going to be stored in the fridge is also important. For instance, cooling of bottles with liquids requires much more energy than air cooling (Belman-Flores, Barroso-Maldonado, Rodríguez-Muñoz, & Camacho-Vázquez, 2015; James Onarinde, & James, 2017).

Table 6
Refrigerator loading capacity.

Household type		Country					Total no.(%)
		France	UK	Portugal	Romania	Norway	
YSM	Half full	1	2	1	3	1	8 (11)
	Full and overpacked	4	2	1	2	2	11 (14)
	Quite empty	–	1	–	–	2	3 (4)
	Ns	–	–	1	–	–	1(1)
YF	Half full	–	2	1	2	1	6(8)
	Full and overpacked	5	3	3	1	3	15(20)
	Quite empty	–	–	–	2	–	2(3)
	ns	–	–	2	–	1	3(4)
ELD	Half full	1	4	1	2	–	8(11)
	Full and overpacked	4	–	4	1	4	13(17)
	Quite empty	–	–	–	2	–	2(3)
	ns	–	1	1	–	1	3(4)
Total		15	15	15	15	15	75(100)

ns-not specified.

3.7. Presence of Listeria monocytogenes

From the total of 53 refrigerators sampled in our study, *Listeria monocytogenes* was confirmed in three refrigerators: one belonging to YSM (Romania), one to YF (Romania), and one to ELD (Portugal). In another fridge from Portugal *Listeria* was present, but it was not confirmed as *L. monocytogenes*. Prevalence of *Listeria* spp. in domestic refrigerators has already been demonstrated in different countries. For example, in Portugal from a total of 86 samples, incidence of *L. monocytogenes* was about 3.5% (Azevedo et al., 2005). *Listeria innocua* was identified in 1% samples collected from Portuguese and French refrigerators (Azevedo et al., 2005; Dieuleveux Collobert, Dorey, & Guix, 2005) and up to 2.4% in Italy (Vegara et al., 2014).

Kennedy et al. (2005) concluded that urban householders' refrigerators in Ireland are more likely to have pathogens than rural householders, while young adults under 25 years of age are even more likely to have one or more extra pathogens present in their refrigerators. Although this study was performed for a relatively low number of households, positive samples were found both in urban and rural refrigerators. Despite the incidence of pathogens, such as *Listeria monocytogenes,* is low, microbiological results correlated to refrigerators' temperature indicate the possibility of psychotrophic pathogen growth (James et al., 2017). To better relate the incidence of listeriosis in vulnerable groups with temperature variations in consumers' refrigerators, larger scale experiments are required for risk assessment.

The presence of *Listeria* spp. in the fridge can be associated with storage of RTE and unwashed vegetables (Breer & Baumgartner, 1992; James et al., 2017) and/or with poor hygiene (Maktabi, Jamnejad, & Faramarzian, 2013). To avoid cross-contamination, it is important to wash vegetables before placing them in the fridge, to store all the food packed, and to frequently clean the refrigerator.

3.8. Questionnaire data

The questionnaire assessed the knowledge about refrigeration temperature and the perceived temperature of the refrigerators considering the education level of the respondents and was answered by respondents from households with vulnerable persons. A quarter of the answers coming from households with ELD, having a low education level, showed lack of knowledge on the refrigeration temperature that is supposed to be in the fridge (Fig. 2A) and indicated that respondents were not aware of the real temperature in their refrigerators (Fig. 2B). However, ranging from 11 to 17%, according to their level of education, respondents from households with ELD considered that the temperature should be above 6 °C. The knowledge level (Fig. 2A) was correlated with the perceived values of temperature (Fig. 2B) ($R^2 = 0.525$, $p < 0.001$).

In the case of households with IDP having a low education level, the percentage of the people who did not know the refrigeration temperatures was similar to the one registered for ELD (Fig. 2C). However, in this case, the percentage of the people who did not have the knowledge of the refrigeration temperature was 24.4% for the people with low education, and inversely correlated with the level of education, being 13.3% for people with high education. The optimistic bias probably is present since the perception was better than the knowledge (Fig. 2D) and there was correlation between perceptions and knowledge ($R^2 = 0.626$ and $p < 0.000$). It appears that respondents from households with IDP are more aware than ELD on the refrigeration temperatures, however, there is an important percentage that do not possess the knowledge, or is mistaking the refrigeration temperatures and this could more likely expose them to risks.

The study targeted also households with pregnant women (n = 318) and YSM (n = 118), but segmentation was less relevant for these cases since the sample was too small compared to the other groups (ELD n = 1287; IDP n = 946). Nonetheless, only in 13.2% of the households where pregnant women live, respondents were not aware of the temperature in their fridges and in 13.9% were under the impression that temperature in their fridges should be above 6 °C. From the total number of households with YSM, 18.6% were not aware on the temperature in their fridge and 9.32% considered the right value being above 6 °C. The perceived values are lower demonstrating again the validity of the hypothesis of optimistic bias.

Our results demonstrated that ELD is the most exposed category to food safety risks and the less educated ones are more exposed than all the other categories. Thus, strategies focussed on the safety of the cold chain should separately try to address the most vulnerable categories and in this case the age could be a barrier in communication, but also technology, while the intricate world in which we are living and undoubtedly the disparities within the European consumers could complicate more this effort. Moreover, attention should be paid to the IDP category that should be periodically reminded on the importance of keeping refrigerator at the right temperatures.

The other categories of vulnerable persons should receive an equal interest and the low educated ones should not be left outside the educational circle.

4. Conclusions

For the first time, investigation of refrigeration temperature in five European countries, conducted in households with vulnerable groups and high risk-takers, is reported. A positive finding was that young men

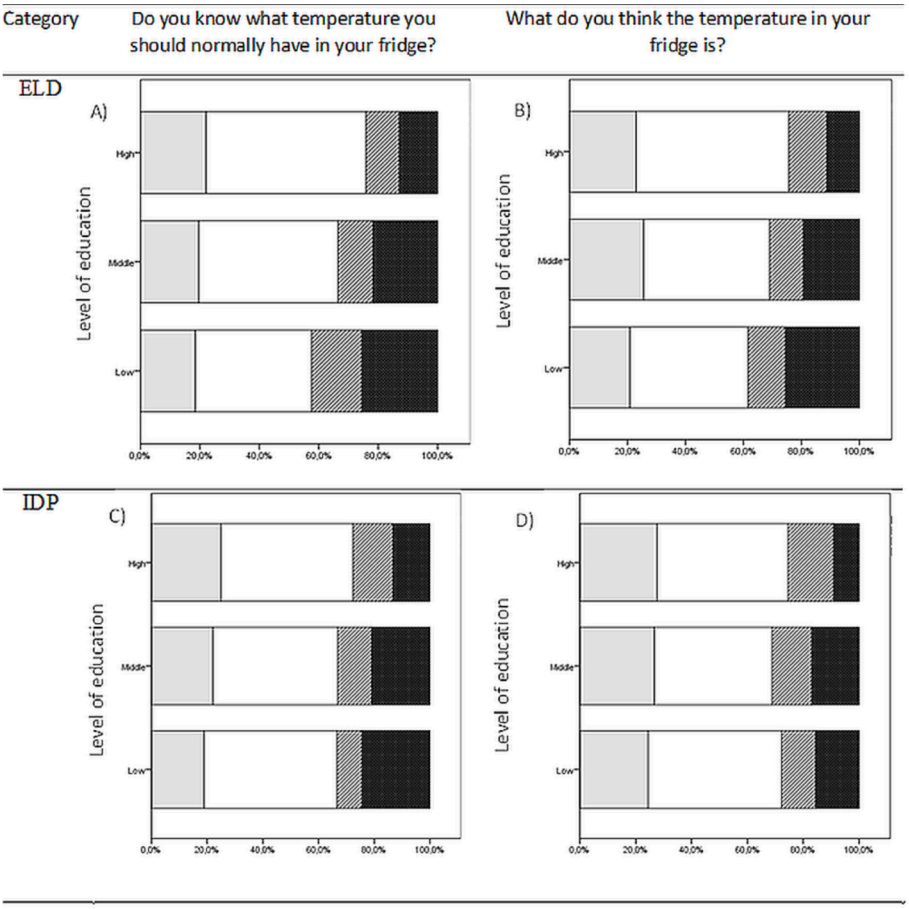

Fig. 2. Knowledge and perceived refrigerator temperature of the respondents from households with vulnerable groups. Percent of the vulnerable people who answered: <4 °C, 4-6 °C, >6 °C, don't know (ELD = elderly, IDP= immunodeficient persons).

are not confirmed to be risk-takers in relation to cooling practices, and families with young children and immunodeficient persons appear to be the most aware about refrigeration practices. Meanwhile, inadequate refrigeration practices may contribute towards higher incidences of illnesses, such as listeriosis, in the ELD population. The decisions of low-income category of elderly in Romania to switch the fridge off during the winter, and in different countries to not invest in new refrigerator equipment, can be considered to increase food risks. The microbiological results indicated a low prevalence of *L. monocytogenes* across the investigated countries, with a few cases found in Romanian households. A suitable questionnaire demonstrated that elderly persons with low education are the most susceptible group to food risks from all the vulnerable categories and that targeted strategies should differently address each susceptible category. These findings indicate that more effort is needed in terms of legislation aimed to regulate specific requirements for domestic refrigerators. The market should also support these safety initiatives by providing easy access to instruments for monitoring temperature inside the fridge or redesigning fridges to be more user-friendly with consumers in respect to temperature control (temperature gadgets easy to read, apps, warning signs and alarms, cold air circulation). Meanwhile, the documentation that comes with new fridges should also contain information on optimum fridge temperatures and storage advice.

To reduce the food safety risk at home, education and communication campaigns remains the best tool to address vulnerable consumers across Europe, if messages are tailored for each country specific problems and cover the whole diversity of consumers. For example, specific guidance on refrigeration temperatures should be provided, in each country by the national food safety authorities.

CRediT authorship contribution statement

Loredana Dumitrașcu: Writing - review & editing. **Anca Ioana Nicolau:** Conceptualization, Supervision, Writing - review & editing. **Corina Neagu:** Writing - original draft. **Pierrine Didier:** Writing - review & editing. **Isabelle Maître:** Writing - review & editing. **Christophe Nguyen-The:** Writing - review & editing. **Silje Elisabeth Skuland:** Formal analysis. **Trond Møretrø:** Writing - review & editing. **Solveig Langsrud:** Writing - review & editing. **Monica Truninger:** Investigation. **Paula Teixeira:** Writing - review & editing. **Vânia Ferreira:** Investigation. **Lydia Martens:** Writing - review & editing. **Daniela Borda:** Writing - original draft, Formal analysis.

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