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Analysis of domestic refrigerator temperatures and home storage time distributions for shelf-life studies and food safety risk assessment

Anna Roccato [a,*], Mieke Uyttendaele [b], Jeanne-Marie Membré [c]

[a] Risk Analysis and Public Health Department, Istituto Zooprofilattico Sperimentale delle Venezie, Viale dell'Università 10, 35020 Legnaro (PD), Italy
[b] Laboratory of Food Microbiology and Food Preservation, Faculty of Bioscience Engineering, Ghent University, Coupure links 653, B-9000 Ghent, Belgium
[c] INRA, UMR1014 SECALIM, Oniris - La Chantrerie, Route de Gachet, CS40706, 44 307 Nantes Cedex 3, France

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ABSTRACT

In the framework of food safety, when mimicking the consumer phase, the storage time and temperature used are mainly considered as single point estimates instead of probability distributions. This singlepoint approach does not take into account the variability within a population and could lead to an overestimation of the parameters. Therefore, the aim of this study was to analyse data on domestic refrigerator temperatures and storage times of chilled food in European countries in order to draw general rules which could be used either in shelf-life testing or risk assessment. In relation to domestic refrigerator temperatures, 15 studies provided pertinent data. Twelve studies presented normal distributions, according to the authors or from the data fitted into distributions. Analysis of temperature distributions revealed that the countries were separated into two groups: northern European countries and southern European countries. The overall variability of European domestic refrigerators is described by a normal distribution: N (7.0, 2.7) °C for southern countries, and, N (6.1, 2.8) °C for the northern countries. Concerning storage times, seven papers were pertinent. Analysis indicated that the storage time was likely to end in the first days or weeks (depending on the product use-by-date) after purchase. Data fitting showed the exponential distribution was the most appropriate distribution to describe the time that food spent at consumer's place. The storage time was described by an exponential distribution corresponding to the use-by date period divided by 4. In conclusion, knowing that collecting data is time and money consuming, in the absence of data, and at least for the European market and for refrigerated products, building a domestic refrigerator temperature distribution using a Normal law and a time-to-consumption distribution using an Exponential law would be appropriate.

1. Introduction

The European policy on food safety has substantially changed since 2002. In order to assure a high level of protection of human health, the approach from farm to fork has been established and the main responsibility for food safety belongs to the Food Business Operator (FBO) (White Book, EU Regulation 178/2002).

In order to manage safety within the production, processing and retail of food, the application of process hygiene and food safety criteria, a self-checking system and HACCP (hazard analysis and critical control point) are the main tools available for the FBOs. However, these tools are used only until the consumer purchases the food product. After purchase, it is the consumer who decides how to store and handle foods.

Unfortunately, food-borne outbreaks still occur in the EU on a regular basis. It has been reported that over 50% of strong-evidence *Salmonella* outbreaks can be traced to a home setting (EFSA and ECDC, 2014). Many of these cases are associated with the most common faults in domestic food hygiene practice, such as inappropriate storage, inadequate cooking, and/or cross-contamination (De Jong, Verhoeff-Bakkenes, Nauta, & De Jonge, 2008; Redmond & Griffith, 2003; Roccato et al., 2015; Sampers et al., 2012). Several factors contribute to the occurrence of food-borne illness outbreaks at home. Most food is prepared at home, thereby increasing the likelihood for food handling mistakes to occur. In addition, most consumers consider the domestic environment (home) as a safe place (optimistic bias) (Tachè & Carpentier, 2014; Byrd-Bredbenner, Berning, Martin-Biggers, & Quick, 2013), thus underestimating the role of personal handling of products in contamination in the domestic environment.

Apart from consumer behaviour at home, the changing eating habits of consumers have an impact on food safety as well. There is an increased demand for convenience foods such as Refrigerated Processed Foods of Extended Durability (REPFED) and fresh-like, ready-to-eat food products with up to several weeks of shelf-life such as pre-packed meat, fishery products or bagged salads (Daelman, Jacxsens, Membré, Sas, Devlieghere and Uyttendaele, 2013b). These are often mildly

* Corresponding author.
E-mail address: aroccato@izsvenezie.it (A. Roccato).

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processed foods with no or few preservatives present, and which mainly rely on modified atmosphere packaging and respect of the cold chain (storage at 4 to max. 7 °C) to ensure safety and quality of product until the end of shelf-life (Ragaert, Devlieghere, & Debevere, 2007). Pathogenic microorganisms may occasionally be present, usually infrequently and at low numbers, in these types of foods, but if products are stored at the appropriate temperature and shelf-life is respected, the risk for consumers of food-borne disease is usually low (Daelman, Jacxsens, Devlieghere and Uyttendaele, 2013a). It is well recognized that temperature is one of the major controlling factors of food quality and food safety because of its influence on microbial growth rates. In fact, bacterial growth (of both pathogenic and spoilage organisms), and subsequently food's shelf-life, mainly depends on the temperature and time of storage.

Therefore, the performance of the cold chain is very important in assuring product quality and safety. Temperature abuse occurs along the food chain and thus, temperature control is especially critical in the last three steps of the cold chain (display cabinets, transport after shopping and domestic refrigerators) (Derens-Bertheau, Osswald, Laguerre and Alvarez, 2015). In particular, one of the most sensitive parts of the cold chain is domestic storage, where in some cases, mean refrigerator temperatures can be in the range of 8–10 °C (James, Evans, & James, 2008).

In addition, several studies have pointed out that consumers do not always respect instructions on time and temperature of storage or preparation of refrigerated foods, as indicated on the shelf-life label (Ceuppens, Van Boxstael, Westyn, Devlieghere, & Uyttendaele, 2016; Daelman, Jacxsens, Membré, Sas, Devlieghere and Uyttendaele, 2013b; Marklinder and Erikkson, 2015; Van Boxstael, Devlieghere, Berkvens, Vermeulen, & Uyttendaele, 2014).

Therefore, in order to meet an appropriate level of protection, it is of paramount importance that both FBOs and risk assessors take into account consumer behaviour – in particular domestic storage temperature and storage time – when assessing food safety. In addition, under Article 3 of Regulation (EC) No 2073/2005, FBOs are obliged to ensure that the food safety criteria applicable throughout the shelf-life of products can be met under reasonably foreseeable conditions of distribution, storage and use. Concerning temperature abuse at the consumer phase, the EU community reference laboratory for *Listeria monocytogenes* suggested using either the relevant recorded temperature for the country (75th percentile of the observed home refrigeration temperatures), or if such data is not available, 12 °C (EU-RL, 2014). On the other hand, for the storage time, the shelf-life test is carried out up to the end of the shelf-life. However, it is to be expected that not all items of a batch of food product are stored up to and consumed on the last day of its shelf-life. Literature data (Daelman, Jacxsens, Membré, Sas, Devlieghere and Uyttendaele, 2013b) reported that chilled food is usually consumed before the end of the shelf-life and that only a small proportion of consumers do not respect the use-by-date. Therefore, when establishing the shelf-life of a food product, the risk is over estimated if it is considered that every consumer eats food at the end of the shelf-life.

When establishing the use-by-date of chilled, pre-packed, ready-to-eat food products or performing risk assessments, the use of single-point estimates is far from reality. Instead of using single-point estimates of the variables, it is preferable to use distributions which characterize the full range of potential values and their likelihood of occurrence (Membré & Valdramidis, 2016a; Membré & Guillou, 2016b). In fact, distributions reflect the variability of the parameters within a population, allowing for more informed decisions. Taking this variability in consideration, recently, Gogou, Katsaros, Derens, Alvarez, and Taoukis (2015) developed a cold chain database which contains a large collection of time-temperature profiles from different stakeholders, associated with a probabilistic tool in order to run simulation scenarios of time-temperature evolution of food along the cold chain.

The main objectives of this study were to: first, collect data on domestic refrigerator temperatures and time to consumption of chilled food and fit distributions to the available data; second, define a general rule able to describe, in terms of probability distribution, the domestic refrigerator temperature and the storage time of chilled food in European countries. Data on consumer surveys were collected and organized in order to fit a parametric distribution to the observed data. The key advantage is that the distribution is defined by a limited number of parameters, which can easily be shared and used within different situations, thus providing a useful tool for both FBOs and risk assessors.

Table 1
Studies on *domestic refrigerator temperatures* (NR: not reported). Studies kept in the temperature analysis are marked in grey.

Reference	Country	Sample size	Format of data provided	Position	Recording time	Device
Laguerre, Derens, & Palagos, 2002	FR	n = 120	Mean, SD, percentile	Top, middle and bottom shelves	Every 2–8 min for 7 days	Data logger
WIV-ISP, 2004	BE	n = 3001	Mean, percentile	NR	NR	NR
Azevedo et al., 2005	P	n = 86	Table of frequency	NR	NR	Digital thermometer
Kennedy et al., 2005	IR	n = 100	Table of frequency	Middle shelf	Every 10 min for 72 h	Data logger
Taoukis, Giannakourou, Koutsoumanis, & Bakalis, 2005	GR	n = 250	Mean, SD	NR	7 days	Data logger
Terpstra, Steenbekkers, de Maertelaere, & Nijhuis, 2005	NL	n = 31	Min, max, percentile	Door	24 h	Glass thermometer
Breen et al., 2006	UK	n = 24	Min, max, mode, percentile	NR	NR	Glass thermometer
Derens, Palagos, & Guilpart, 2006	FR	n = 251	Mean, SD	NR	NR	NR
Carrasco, Pérez-Rodríguez, Valero, García-Gimeno, & Zurera, 2007	SP	n = 30	Mean, SD, percentile	NR	Every 30 s over 24 h	Data logger
Garrido, García-Jalón and Vitas, 2010a	SP	n = 33	Min, max, mean, SD	Top, middle and bottom shelves	NR	Calibrated probe
Koutsoumanis, Pavlis, Nychas, & Xanthiakos, 2010	GR	n = 100	Table of frequency	Top, middle, bottom shelves and door	Every 5 min for 24 h	Data logger
WRAP (waste and reduction action programme), 2010	UK	n = 50	Table of frequency	Top, middle and bottom shelves	4 days, every 1 min	Data logger
IAFP's European Symposium on Food Safety, 2013a	IT	n = 106	Temperature values	Top, bottom and door	Every 15 min for 7 days	Data logger
Vegara et al., 2014	IT	n = 84	Mean, percentile	Middle shelf	24 h	Digital thermometer
Marklinder and Erikkson, 2015	SW	n = 1770	Mean, SD	Back and front of top, middle and bottom shelves	24 h	Refrigerator thermometer