



Raw-egg based-foods consumption and food handling practices: A recipe for foodborne diseases among Romanian and Portuguese consumers

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ABSTRACT

Salmonellosis is the second most common zoonosis in humans after campylobacteriosis. Eggs and egg products are the foods most commonly associated with *Salmonella* outbreaks. Also, inadequate hygiene practices performed by consumers at home contribute to the prevalence of foodborne diseases. The elderly, children, and pregnant women are the most vulnerable individuals. Thus, the objective of this study was to analyse Romanian and Portuguese consumers' self-reported consumption of raw-egg based-foods, food and hand hygiene practices, and to check if vulnerable consumer groups mediate the relationship between consumption of raw-egg based-foods and hygiene practices since they have weak immune systems. Significant correlations were found between the number of foodborne events and the number of Romanian and Portuguese consumers who did not report proper raw-egg handling and hand hygiene practices. An ordinary regression model indicated an increased consumption frequency of raw-egg based-foods reported by Romanian and Portuguese men, consumers aged <55 years, and from the category of vulnerable consumers, families with pregnant women, and families with children thus exposing themselves to a higher risk of foodborne diseases when compared with Romanian and Portuguese women and consumers aged >55 years. Structural equation modelling (SEM) indicated that there is a negative link between consumption frequency of raw-egg based-foods and food and hand hygiene practices for both Romanian and Portuguese consumers. Vulnerable consumers mediate the relationship between consumption frequency and hygiene practices, suggesting that Romanian families with elderly members and families with children dampened the negative relationship between consumption of raw-egg based-foods and self-reported hygiene practices, the contrary being observed Portuguese families with children and families from both countries with pregnant women. Recommendations for multi-faceted approaches regarding educational campaigns are made in order to improve consumers' knowledge and food handling practices.

1. Introduction

Eggs can be consumed either raw or cooked, although the first implies the risk of salmonellosis, an infection caused by the ingestion of *Salmonella*. Egg contamination can occur either internally (vertical transmission of the pathogen) in poultry or externally (horizontal transmission from poultry droppings) (CDC (Centers for Disease Prevention and Control), 2021). Salmonellosis is the second most common zoonosis in humans after campylobacteriosis with 52,702 confirmed human cases in 2020 (EFSA & ECDC, 2021). In Europe *Salmonella* was the most frequently encountered foodborne pathogen in humans accounting for 22.5% (694 salmonellosis outbreaks) of the total

foodborne outbreaks and causing the highest number of diseases (3,686; 18.41% of all the outbreak-related diseases) and hospitalisations (812; 48.5% of all the outbreak-related hospitalisations) (EFSA & ECDC, 2021).

Eggs and egg products were the foods most commonly associated with *Salmonella* being responsible for 5.3% of the *Salmonella*-related strong-evidence foodborne outbreaks in 2020 (EFSA & ECDC, 2021).

Symptoms associated with salmonellosis are abdominal cramps, nausea, vomiting, and diarrhoea. The disease can be life-threatening for susceptible consumers, such as elderly (>65 years old), children (<5 years old), pregnant women and immune-compromised persons (CDC (Centers for Disease Prevention and Control), 2021). Despite the

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food safety scandals involved in the egg industry from previous years, like the *Salmonella* outbreak in the US in 2015 (Whiley & Ross, 2015), the contamination of eggs with Fipronil pesticide in EU in 2017 (European Commission, 2017), and the EU multi-country salmonellosis outbreak (838 confirmed cases) that occurred during 2016–2018 and originated from Poland (Pijnacker et al., 2019), eggs are still one of the foods consumed on a weekly basis (e.g., 2–3 times/week) (Hessel et al., 2019) or even daily (one egg/day) (Islam, Sayeed, Akhtar, Hossain, & Liza, 2018). Involved in the most frequently cases of salmonellosis are raw-egg products like: sauces and spreads made with raw eggs (e.g., mayonnaise, egg butter), desserts made without an effective cooking step (e.g., tiramisu, chocolate mousse), and drinks containing raw eggs (e.g., eggnog, raw egg high protein smoothies) (NSW (New South Wales) Food Authority, 2016). Consumers' food safety knowledge and practices during meal preparation play an important role in reducing foodborne diseases that take place at home as they are the final line of defence in the food chain (Redmond & Griffith, 2003). The occurrence of foodborne events has been previously associated with inadequate food handling practices like infrequently insufficient milk heating or not heating thoroughly cooked food (Chen et al., 2018). To reduce the risk of *Salmonella* infection, consumers are recommended to avoid consumption of undercooked or raw meat and egg products (Cardoso et al., 2021; Tomaszewska, Trafialek, Suebpongsoang, & Kolanowski, 2018).

Currently, there are no studies that emphasise the risk to which consumers are exposed by the consumption of raw-egg based-foods. Our study presents relationships between consumption frequency of raw-egg based-foods - foodborne events and hand hygiene practices during food handling. Thus, this paper reveals which consumer groups are at high risk of foodborne disease caused by raw-egg based-foods consumption and hygiene practices and makes recommendations on how food safety authorities could conduct campaigns to improve consumers' food handling behaviour at home.

Structural equation modelling (SEM) was used for detailed investigations regarding consumption frequency of raw-egg based-foods and hand hygiene practices during food handling, and mediation effects of vulnerable consumers (if vulnerable consumers mediate the relationship between raw-egg based-foods consumption and food and hand hygiene practices). SEM has been previously used in other studies for analysing the links between consumer's food safety risk perception, trust and information (Ha, Shakur, & Pham Do, 2020), and food safety knowledge, attitude, and practices models (KAP) (Mihalache, Dumitraşcu, Nicolau, & Borda, 2021). To our knowledge, this is the first study to conduct and highlight this kind of research.

Very few consumers are aware of the harm that risky food, such as raw-egg based foods, can cause. This is indicated by studies where eggs were seen as a potential cause of food poisoning by only 3.6% of Italian consumers (Langiano et al., 2012), 8.9% of Chinese consumers (Gong, Wang, Yanh, & Bai, 2016) and 19% of Portuguese consumers (Carbas, Cardoso, & Coelho, 2013). Also, foodborne outbreaks have been previously correlated with consumers' food safety and hygiene practices during food handling (EFSA & ECDC, 2021; Wu et al., 2018). Thus, to evaluate the Romanian and Portuguese consumers' exposure to food poisoning we hypothesised the following:

H1. There is a negative link between consumers that frequently eat raw-egg based-foods and their self-reported food and hand hygiene practices.

Elderly consumers, children, and pregnant women are among the most vulnerable individuals to foodborne diseases (FDA, 2020). High frequencies of food safety errors (i.e., defrosting or storing food at room temperature) were previously observed in families that had groups susceptible to foodborne diseases (Langiano et al., 2012). Due to higher susceptibility to food poisoning, vulnerable consumers are at an increased health risk if they consume risky food and engage in unsafe food handling practices when compared to consumers that are not part

of the vulnerable group. Hence, we tested the interaction effects between vulnerable consumers - raw-egg based-foods consumption and their mediation effects on self-reported food and hand hygiene practices:

H2a. The interaction household of families with elderly members (>65 years) - consumption frequency of raw-egg based-foods has a significant mediation effect on consumers' self-reported food and hand hygiene practices.

H2b. The interaction household of families with children (<6 years) - consumption frequency of raw-egg based-foods has a significant mediation effect on consumers' self-reported food and hand hygiene practices.

H2c. The interaction household of families with pregnant members - consumption frequency of raw-egg based-foods has a significant mediation effect on consumers' self-reported food and hand hygiene practices.

Our investigation was conducted considering that an increased consumption frequency of raw-egg based-foods correlated with the fact that eggs are the most known source of *Salmonella* infection could lead to an increased occurrence of foodborne diseases at home. Furthermore, the risks of infection could be even higher if food safety practices are not performed during food handling. Hence, the objectives of this study were as following:

- To evaluate if there is a correlation between Romanian and Portuguese consumers' consumption frequency of raw-egg based-foods and foodborne events;
- To assess the exposure of Romanian and Portuguese consumers (especially vulnerable groups) to possible *Salmonella* infection by their consumption frequency of raw-egg based-foods using regression analysis;
- To use SEM for Romanian and Portuguese consumers in order to: i) test the connection between raw-egg based-foods consumption and food and hand hygiene practices, ii) check if vulnerable consumers significantly mediate this connection, and iii) run a multi-group effect to see if there are significant difference between the Romanian and Portuguese causal model.

2. Materials and methods

The work from this study is part of the SafeConsume project (Horizon 2020; grant agreement No 727580, <http://safeconsume.eu/>) that evaluates consumers' practices from shopping to cooking and aims to reduce the risks of foodborne diseases among consumers from European countries.

2.1. Survey design

Apart from demographical details, the survey consisted of sections that targeted the consumption frequency of raw egg-based foods, hygiene practices, and occurrence of foodborne events as follows: i) consumption frequency of dishes/side dishes/homemade desserts prepared with raw eggs (three questions with 4-point Likert scale answers, where 1 is never or less than once a month and 4 is 1–3 times/day), ii) food and hand hygiene practices: the probability of touching raw eggs with bare hands, the probability of washing hands after touching raw eggs (11-point Likert scale: 1 – no chance/almost no chance; 11 – certain/practically certain), egg cleaning methods (nominal scale; yes/no), washing hands after touching raw meat/eggs and washing hands after mopping up spillages from poultry/eggs (nominal scale; yes/no), iii) occurrence of foodborne events in the respondents' households in the last year (one question with a 4-point ordinal scale; 0 – no foodborne events; 3 – three or more foodborne events). The survey was developed based on the food safety practices recommended by WHO Five Keys to Safer Food practices (WHO, 2006). Based on Cronbach's alpha coefficient the data set had a

good level of reliability ($\alpha = 0.8$).

2.2. Consumer recruitment and data collection

Consumer recruitment was conducted via Dynata, a global online market research that provides accurate, reliable data from one of the largest collections of permissioned first-party data (Dynata, <http://www.dynata.com/>). The population sample was stratified based on the regions of Romania and Portugal that represent the NUTS II-level division in the European Union, and the education level of the respondents. The questionnaire was conducted between December 2018 and April 2019.

2.3. Data analysis

The data was not normally distributed as indicated by the Shapiro-Wilk test ($p > 0.05$). Descriptive statistics, Spearman correlations (ρ ; significant at $p < 0.01$), regression analyses, and exploratory factor analysis (EFA) were performed with SPSS 26 (IBM Software Group, Chicago, IL). Confirmatory factor analysis (CFA) and structural equation modelling (SEM) were performed with Analysis of Moment Structures - AMOS 20 (IBM Software Group, Chicago, IL).

The regression models displayed a significant improvement when they were compared with the null model (Omnibus Test; $p < 0.01$). The goodness of fit of the model was evaluated with the Pearson and Deviance tests which when they are non-significant, indicate that the model fits the data well ($p > 0.05$) (Field, 2018). The assumption of proportional odds or the parallel lines test assumes that the slope coefficients are the same across the response categories. This assumption is accepted when $p > 0.05$ and indicates that the data is adequate for regression analysis (Osborne, 2017).

The data correlation and its adequacy were tested with the Kaiser-Meyer-Olkin test (acceptable if > 0.6) and Bartlett's test of sphericity ($p < 0.05$). EFA was applied to determine the underlying structure of our data. Extraction of factors was based on the eigen value > 1 and on the scree plot. Varimax rotation method was used to identify the individual variables embedded in each factor. Items were retained only if they had communalities > 0.4 and data was considered reliable if Cronbach's Alpha > 0.7 . Discriminant validity was examined with pattern matrix, while convergent validity was present if the items had loadings > 0.5 . Based on the result from EFA we further conducted confirmatory factor analysis (CFA) to assess the reliability, and validity of the measures of the studied constructs before using structural equation modelling (SEM). Both methods were performed with Analysis of Moment Structures - AMOS 20 (IBM Software Group, Chicago, IL). For the CFA, the convergent validity was acceptable if the average variance extracted (AVE) was > 0.5 , while discriminant validity was considered when the square root of AVE was larger than its relevant coefficient and when maximum squared variance (MSV) $< AVE$. Goodness of model fit was based on Chi-square to the degree of freedom $\chi^2/df < 5$, comparative fit index (CFI) > 0.8 , goodness of fit index (GFI) > 0.9 , adjusted goodness of fit index (AGFI) > 0.8 , the root mean square error of approximation (RMSEA) is < 0.1 , and the standardized root mean square residual (SRMR) < 0.09 (Gaskin, 2016). The multi-group effect was applied to evaluate if any of the relationships revealed by SEM for the Romanian respondents are stronger or weaker than the relationships revealed in SEM for the Portuguese respondents (significant at $p < 0.05$).

In order to test if vulnerable consumers mediate the relationship between consumption frequency of raw-egg based-foods – food and hand hygiene practices in the SEM analysis, we computed new variables which are named interactions. The interactions consisted in combining the variables of households of families with vulnerable members (pregnant members, elderly members > 65 years old, and families with children < 6 years old) with the consumption frequency of foods made with raw eggs. Hence, the variables used for testing the mediation effects were: “PregWomen_x_ConsFreq” (households with pregnant members

who frequently consume raw-egg based-foods), “Child-Memb_x_ConsFreq” (households with children who frequently consume raw-egg based-foods), and “ElderlyMemb_x_ConsFreq” (households with elderly members who frequently consume raw-egg based-foods).

All analyses were run both for the Romanian and Portuguese consumers in order to assess their food and hygiene practices and to see if significant differences exist between these populations.

3. Results and discussions

3.1. The demographic profile of the respondents

Table 1 contains the demographic characteristics of the respondents.

3.2. Consumption frequency of dishes/side dishes/homemade desserts prepared with raw eggs and food safety practices

Consumers' consumption frequency of side dishes, dishes, and homemade desserts prepared with raw eggs is shown in Table 2.

Kruskal-Wallis Test revealed that there is a significant difference between the consumption frequency of raw-egg based-dishes/side dishes, indicating that the Romanian respondents consume the mentioned foods more frequently than the Portuguese respondents ($p < 0.05$). The differences might be attributed to the fact that Romanian consumers perceive eggs as a healthy food and from a cultural point of view eggs are often present in Romanian's breakfast menu. The Romanians appetite for eggs was confirmed by a survey performed in 2017, its results indicating that 8 of 10 Romanians consume eggs on a weekly basis (MeatMilk, 2017). No significant differences were observed regarding the consumption of raw-egg based-desserts ($p > 0.05$).

Our findings are also in line with data known about consumers from other countries. Italian consumers reported that they mostly eat cooked eggs (48.9%), but there was a small percentage of raw egg consumption

Table 1
The demographic profile of the respondents.

Variable	RO	PT
	Frequency, (%)	
Gender (N = 1918)		
Female	499 (50.7)	454 (48.7)
Male	486 (49.3)	479 (51.3)
Age (N = 1918)		
16–34	307 (31.2)	298 (32)
35–54	359 (36.5)	347 (37.1)
55–64	155 (15.7)	142 (15.2)
>65	164 (16.6)	146 (15.7)
Educational level (N = 1904)		
Low	10 (1)	99 (10.7)
Medium	305 (31)	350 (37.8)
High	666 (67.9)	478 (51.6)
Inhabitancy (N = 1918)		
In a city (more than 100,000 inhabitants)	491 (49.8)	506 (54.2)
In a town (more than 10,000 inhabitants)	384 (39)	318 (34.1)
In the countryside/rural district	110 (11.2)	109 (11.7)
Are you or any of the members of your household currently pregnant? (N = 1918)		
No	918 (93.2)	884 (94.7)
Yes	67 (6.8)	49 (5.3)
How many children under the age of 6 live in your household? (N = 1732)		
None	765 (84.8)	702 (84.6)
One	120 (13.3)	110 (13.3)
Two	16 (1.6)	18 (2.2)
Three or more	1 (0.1)	0
How many people over the age of 65 live in your household? (N = 1732)		
None	617 (68.4)	635 (76.5)
One	161 (17.8)	107 (12.9)
Two	119 (13.2)	86 (10.4)
Three or more	5 (0.5)	2 (0.2)

RO = Romania; PT = Portugal; Educational level: Low = ISCED 0, 1, 2; Medium = 3, 4; High = 5, 6, 7, 8 (ISCED, 2020); N = number of valid answers.

Table 2

Respondents' frequencies consumption of dishes, side dishes, and homemade desserts that are prepared with raw eggs.

Variable	RO	PT
	Frequency, (%)	
How often do you or other members of your household eat side dishes that are prepared with raw eggs (e.g., homemade mayonnaise, aioli) at home, on average? (N = 1918)		
Never or less than once a month	350 (35.5)	645 (69.1)
1 to 3 times per month	464 (47.1)	180 (19.3)
1 to 6 times per week	165 (16.8)	104 (11.1)
1 to 3 times per day	6 (0.6)	4 (0.4)
How often do you or other members of your household eat dishes at home that are prepared with raw eggs alone (e.g., homemade tartare sauce; smoothie/juice) and which are not fully heated up during preparation, on average? (N = 1918)		
Never or less than once a month	707 (71.8)	805 (86.3)
1 to 3 times per month	160 (16.2)	69 (7.4)
1 to 6 times per week	109 (11)	54 (5.8)
1 to 3 times per day	9 (0.9)	5 (0.5)
How often do you or other members of your household eat sweet homemade desserts at home that contain raw eggs (e.g., homemade tiramisu, homemade chocolate mousse) and which are not fully heated up during preparation? (N = 1918)		
Never or less than once a month	605 (61.4)	596 (63.9)
1 to 3 times per month	244 (24.8)	252 (27)
1 to 6 times per week	130 (13.1)	79 (8.5)
1 to 3 times per day	6 (0.6)	6 (0.6)

RO = Romania; PT = Portugal; N = number of valid answers.

as well (16.1%) which mainly consisted of tiramisu (dessert prepared with raw eggs) (Prencipe, Rizzi, Giovannini, & Migliorati, 2010). In the US more than half of the consumers reported eating raw cookie dough (prepared with raw eggs) (Byrd-Bredbenner et al., 2007) and 40% consumed raw eggs (Fein, Lando, Levy, Teisl, & Noblet, 2011). Similarly, half of the Mexican-American respondents declared they ate risky food such as eggs with runny yolks, soft scrambled eggs or handmade frosting prepared with raw eggs (Parra, Kim, Shapiro, Gravani, & Bradley, 2014). In Australia, 84% of the participants said they did not consume raw egg products at home, but 86% contradicted this affirmation by saying they lick bowls or utensils containing raw eggs mixture (Whiley, Clarke, & Ross, 2017). Ten percent of Brazilian consumers also reported to consume raw or undercooked yolks or omelettes (Hessel et al., 2019). Two studies indicated that over 40% of the Canadian respondents consumed undercooked eggs (Nesbitt et al., 2009; Fraser Health & Vancouver Coastal Health, 2010).

Despite the high consumption frequency of raw egg and raw egg products, the association of these products with food safety risks is low. In the study of Sharif and Al-Malki (2010) half of the Saudi college students were not aware of the food poisoning risks associated with raw eggs consumption and believed that raw eggs are healthier than pasteurised eggs. Osaili, Obeidat, Abu Jamous, and Bawadi (2011) indicated that only half of the Jordanian students knew that consumption of risky foods like fried eggs with a runny or soft yolk, raw homemade cookie dough or cake batter can increase the risks of foodborne diseases. Among young Canadian adults (19–29 years old) only 35% associated eggs with runny yolk with food safety risks (Burke, Young, & Papadopoulos, 2016). Lazou, Georgiadis, Pentieva, McKevitt, and Iossifidou (2012) reported that more than half of the Greek students regarded undercooked eggs as being safe for consumption. Similarly, half of the Canadian consumers were aware of the risks associated with undercooked eggs (Murray et al., 2017). Nonetheless, higher awareness was reported in the study of Hessel et al. (2019) where two thirds of the Brazilian consumers linked egg consumption with potential health harm caused by *Salmonella*, while 90% of the Mexican-American respondents that consumed raw eggs were knowledgeable of possible *Salmonella* infection when eating eggs (Parra et al., 2014). Seventy five percent of Austrian consumers associated *Salmonella* with eggs or poultry (70%) and 75% the Irish consumers knew that consumption of undercooked beef/eggs could cause

food poisoning (Moreb, Priyadarshini, & Jaiswal, 2017). Awareness of *Salmonella* egg contamination is important since the foodborne outbreaks caused by this pathogen are mainly associated with egg consumption (CDC, 2018; WHO, 2015). However, awareness of this pathogen did not discourage the consumption of raw eggs/raw egg products (Parra et al., 2014). This may be due to the fact that consumers prioritise taste when choosing foods and state “I enjoy eggs with a runny center”, “I prefer the taste of rare meat.” (Fischer et al., 2007) or “I do not consider over-easy raw because that is how I like my eggs” (Atheam et al., 2004). Rather than cooking foods to a safe temperature, they adhere to their risky practice, which is further enhanced by optimistic bias: “It won't happen to me.” Six out of ten American consumers believe that the chances of them getting food poisoning are low (International Food Information Council Foundation, 2012).

In Table 3 are shown consumers' self-reported food and hand hygiene practices and occurrence of foodborne events.

A third of the Romanian respondents said that they are certain they would touch raw eggs with their bare hands (34.5%) while the same statement was reported only by 21.9% of the Portuguese respondents. Five percent of the Romanian respondents indicated that there is no

Table 3

Consumers' self-reported food and hand hygiene practices and occurrence of foodborne events.

Variable	RO	PT
	Frequency, (%)	
How likely is it that you would touch the whole eggs with your bare hands? (N = 1885)		
No chance or almost no chance (1 in 100)	34 (3.5)	151 (16.5)
Very slight possibility (1 in 10)	45 (4.6)	130 (14.2)
Slight possibility (2 in 10)	35 (3.6)	53 (5.8)
Some possibility (3 in 10)	59 (6.1)	59 (6.4)
Fair possibility (4 in 10)	53 (5.5)	44 (4.8)
Fairly good possibility (5 in 10)	80 (8.2)	52 (5.7)
Good possibility (6 in 10)	65 (6.7)	36 (3.9)
Probable (7 in 10)	46 (4.7)	43 (4.7)
Very probable (8 in 10)	72 (7.4)	53 (5.8)
Almost sure (9 in 10)	146 (15.1)	94 (10.3)
Certain or practically certain (99 in 100)	335 (34.5)	200 (21.9)
How likely is it that you would wash your hands immediately after touching the raw eggs? (N = 1885)		
No chance or almost no chance (1 in 100)	51 (5.3)	143 (15.6)
Very slight possibility (1 in 10)	68 (7)	121 (13.2)
Slight possibility (2 in 10)	71 (7.3)	82 (9)
Some possibility (3 in 10)	69 (7.1)	79 (8.6)
Fair possibility (4 in 10)	92 (9.5)	58 (6.3)
Fairly good possibility (5 in 10)	90 (9.3)	65 (7.1)
Good possibility (6 in 10)	65 (6.7)	46 (5)
Probable (7 in 10)	56 (5.8)	42 (4.6)
Very probable (8 in 10)	103 (10.6)	77 (8.4)
Almost sure (9 in 10)	104 (10.7)	74 (8.1)
Certain or practically certain (99 in 100)	201 (20.7)	128 (14)
How do you clean eggs before using them? (N = 1496)		
Running tap water	645 (81.3)	598 (85.1)
Kitchen roll/cloth	96 (12.1)	79 (11.2)
Detergent/disinfectant	123 (15.5)	36 (5.1)
Scouring pad/sandpaper	17 (2.1)	45 (6.4)
Antibacterial wipes	32 (4)	17 (2.4)
Other	7 (0.9)	8 (1.1)
None of the above	3 (0.4)	11 (1.6)
In general, when would you normally wash your hands at home? (N = 1918)		
Yes (%)		
After touching raw meat/eggs	756 (76.8)	661 (70.8)
After mopping up spillages from poultry/eggs	748 (75.9)	577 (61.8)
In the last year, how many times did foodborne events occurred in your household (with vomiting and/or diarrhoea)? (N = 1918)		
Yes (%)		
None	647 (65.7)	614 (76.5)
One times	137 (13.9)	97 (10.4)
Two times	81 (8.2)	55 (5.9)
Three or more times	120 (12.2)	67 (7.2)

RO = Romania; PT = Portugal; N = number of valid answers.

chance that they would wash their hands after touching raw eggs, while the same was stated by 15.6% of the Portuguese respondents.

Related to food hygiene, a high percentage of the Romanian and Portuguese respondents (81.3%, respectively 85.1%) said that they clean eggs under running tap water.

Regarding situations when hand washing should occur, 76.8%, respectively 70.8% of the Romanian and Portuguese consumers stated they wash their hands after touching raw meat/eggs. Twelve percent of the Romanian respondents reported the occurrence of three or more foodborne events in the last year, while this occurrence was reported only by 7.2% of the Portuguese respondents. The low percentages of respondents that stated they did experience foodborne diseases could be caused by the fact that consumers often misinterpret the symptoms of food poisoning and many cases remain underreported (WHO Regional Office for Europe, 2017).

Overall, the Romanian respondents were more likely to touch the raw eggs with their bare hands are also more inclined to wash hands after handling raw eggs than the Portuguese respondents ($p < 0.05$). Chi-squared tests indicated a significant association between both Romanian and Portuguese consumers with the cleaning of eggs under running water ($\chi^2 = 8.56; p < 0.01; \chi^2 = 13.82; p < 0.01$) and hand washing after touching raw meat/egg and mopping spillages from poultry/eggs ($\chi^2 = 25.31; p < 0.01; \chi^2 = 44.57; p < 0.01$). The Romanian respondents reported significantly more foodborne events than the Portuguese consumers ($p < 0.05$).

The majority of the respondents declared they normally wash hands after touching raw meat/eggs (73.9%) and after mopping up spillages from poultry/eggs (69.1%).

In the study of Koppel et al. (2015) 64% of the Russian consumers, 50% Estonian consumers, 63% Italian consumers, and 62% Spanish consumers self-reported that they wash hands after handling raw meat or eggs. Low rates of hand washing occurrences were self-reported by Australian consumers, where only 38.7% declared they would always wash their hands after handling eggs (Whiley et al., 2017). Even lower rates were noticed in an observational study where after handling raw eggs used to prepare fried eggs, respectively scrambled eggs, only 15%, respectively 14% of American consumers properly washed their hands (Maughan et al., 2016). The low rates of hand washing during egg handling prove that consumers are unaware of the potential bacterial growth on the shell of the eggs and that washing hands is necessary in order to prevent cross-contamination, respectively the risk of foodborne diseases.

Other studies related to food hygiene indicated that half of Bulgarian students reported to never wash eggs (Stratev et al., 2017), while low percentages of Italian and Spanish consumers, and high percentages of Russian consumers declared they wash eggs before cooking/frying them (Koppel et al., 2015). Among respondents from South Africa and Asia, 80% self-reported the practice of washing eggs before cooking them (Odeyemi et al., 2019).

Washing should be done only when eggs are visibly soiled, otherwise this operation could destroy the protective layer named cuticle, which could lead to higher internal microbial contamination.

Regarding foodborne events, 71% of the respondents did not experience foodborne diseases in the last year, while 12.2%, respectively 9.7% reported that they had one, respectively three or more foodborne events in their household in the last year. The high percentage of respondents that stated they did not experience foodborne diseases could be caused by the fact that consumers often misinterpret the symptoms of food poisoning and many cases remain underreported (WHO Regional Office for Europe, 2017).

3.3. Risk exposure to food poisoning as revealed by correlations between self-reported consumption frequency of raw-egg based-foods, food handling practices, and foodborne events

A preliminary correlation test was performed to check the relation

between the raw-egg based-foods (dishes/side dishes/homemade desserts prepared with raw eggs). The correlations between the consumption frequency of foods prepared with raw eggs are medium to high both for the Romanian and Portuguese respondents ($\rho = 0.57\text{--}0.74$) and significant ($p < 0.001$). This implies that the consumption of these foods is intercorrelated and that an increased recurrence of eating one of this type of dish indicates a higher probability of consuming the other two dishes more often and the other way around. These results indicate higher frequencies of risk exposure to pathogen infection, especially with *Salmonella*.

Table 4 displays the correlations between the foodborne events that occurred in the Romanian and Portuguese respondents' households with the consumption frequency of raw-egg based-foods and self-reported food and hand hygiene practices.

As shown in Table 4 there are significant positive correlations between the occurrence of foodborne events in the Romanian and Portuguese respondent's households in the last year and the consumption frequency of dishes/side dishes/homemade desserts prepared with raw eggs ($\rho = 0.2\text{--}0.28; p < 0.001$). Additionally, there is a positive correlation between foodborne events and handling raw eggs with bare hands both for Romanian and Portuguese respondents ($\rho = 0.28; p < 0.001$, respectively $\rho = 0.24; p < 0.001$) that is backed up by negative significant correlations between washing hands after handling raw eggs, washing hands after mopping up spillages from poultry and the number of foodborne events ($\rho = -0.15$ to $-0.22; p < 0.001$). These correlations imply that a high consumption frequency of dishes made with raw eggs and a low probability of washing hands after handling raw eggs could lead to a higher number of foodborne diseases that occur at home.

Table 5 and Table 6 display the number of foodborne events and the consumption of raw-egg based-foods for the Romanian and Portuguese consumers. We can see that the respondents who reportedly consume raw-egg side dishes 1–3 times/month were the group with the highest rate of no foodborne events (317, respectively 140 for Romanian and Portuguese respondents) followed up by those whose consumption frequency was never/less than once a month (250, respectively 521 for Romanian and Portuguese respondents). Similarly, for dishes made with raw eggs, in households where the consumption was never/less than once a month, there were 500, respectively 645 Romanian and Portuguese respondents who declared they had no foodborne events in the last year. Comparable results were obtained for the homemade desserts prepared with raw eggs, indicating that in households where consumption was never/less than once a month, 438, respectively 490 of the Romanian and Portuguese respondents declared they had no occurrences of foodborne events in the last year.

Table 4

Correlations between the foodborne events that occurred in the respondents' households with the consumption frequency of raw-egg based-foods and self-reported food and hand hygiene practices.

Variable	RO	PT
	ρ	
In the last year, how many foodborne events occurred in your household (with vomiting and/or diarrhoea)?		
Consumption frequency of side dishes prepared with raw eggs	0.2*	0.28*
Consumption frequency of dishes prepared with raw eggs alone	0.26*	0.23*
Consumption frequency of homemade desserts prepared with raw eggs	0.24*	0.25*
How likely is it that you would touch the whole eggs with your bare hands?	0.28*	0.24*
How likely is it that you would wash your hands immediately after touching raw eggs?	-0.15*	-0.21*
Wash hands after touching raw meat/eggs	-0.19*	-0.15*
Wash hands after mopping up spillages from poultry/eggs	-0.22*	-0.18*

RO = Romania; PT = Portugal; ρ = Spearman correlation; * $p < 0.001$.

Table 5
Foodborne events and the consumption of dishes prepared with raw eggs in Romania.

Foodborne events	Raw-egg side dishes consumption frequency			
	Never/less than 1 time/month	1-3 times/month	1-6 times/week	1-3 times/day
None	250	317	79	1
One time	47	63	24	4
Two times	29	36	16	1
Three or more times	24	50	41	3
Foodborne events	Raw-egg dishes consumption frequency			
	Never/less than 1 time/month	1-3 times/month	1-6 times/week	1-3 times/day
None	500	103	41	3
One time	96	23	15	3
Two times	57	13	12	0
Three or more times	45	21	48	3
Foodborne events	Raw-egg homemade desserts consumption frequency			
	Never/less than 1 time/month	1-3 times/month	1-6 times/week	1-3 times/day
None	438	156	52	1
One time	79	33	22	3
Two times	44	25	12	0
Three or more times	43	32	42	0
Legend	Foodborne events ≤50		50–100	>100

Table 6
Foodborne events and the consumption of dishes prepared with raw eggs in Portugal.

Foodborne events	Raw-egg side dishes consumption frequency			
	Never/less than 1 time/month	1-3 times/month	1-6 times/week	1-3 times/day
None	521	140	52	1
One time	66	18	13	0
Two times	36	7	4	0
Three or more times	22	15	16	3
Foodborne events	Raw-egg dishes consumption frequency			
	Never/less than 1 time/month	1-3 times/month	1-6 times/week	1-3 times/day
None	645	49	18	2
One time	83	7	7	0
Two times	45	5	5	0
Three or more times	37	8	24	3
Foodborne events	Raw-egg homemade desserts consumption frequency			
	Never/less than 1 time/month	1-3 times/month	1-6 times/week	1-3 times/day
None	490	181	40	3
One time	59	32	5	1
Two times	30	18	7	0
Three or more times	17	21	26	2
Legend	Foodborne events ≤50		50–100	>100

Table 7
Raw-egg based-foods consumption in relation to consumers' demographic profile.

Variable	Frequency consumption of raw/undercooked egg-based foods					
	RO		PT		RO	PT
	β (SE)		OR (95% CI)		p	
Gender						
Female	0 ^a	0 ^a	1	1		
Male	0.64 (0.13)	0.72 (0.21)	1.89 (1.4, 2.4)	2.14 (0.36; 11.23)	0.00*	0.00*
Age						
16–24	1.03 (0.25)	0.88 (0.38)	2.82 (1.66; 4.79)	2.41 (0.43; 13.33)	0.00*	0.00*
25–34	0.61 (0.24)	0.76 (0.26)	1.84 (1.1; 3.07)	1.14 (0.39; 11.86)	0.02*	0.00*
35–44	0.74 (0.24)	0.29 (0.13)	2.1 (1.31; 3.37)	1.33 (0.24; 7.37)	0.00*	0.00*
45–54	0.6 (0.25)	0.38 (0.24)	1.82 (1.11; 3)	1.45 (0.26; 8.08)	0.01*	0.02*
55–64	0.08 (0.24)	0.38 (0.24)	1.08 (0.66; 1.76)	1.46 (0.28; 7.6)	0.74	0.02*
>65	0 ^a	0 ^a	1	1		
Inhabitancy						
Urban	0 ^a	0 ^a	1	1		
Rural	-0.47 (0.19)	-0.17	0.62 (0.42; 0.91)	0.84 (0.59; 1.14)	0.01*	0.07
Pregnant women						
No	0 ^a	0 ^a	1	1		
Yes	1.39 (0.26)	1.16 (0.18)	4.03 (2.39; 6.8)	3.19 (1.34; 4.52)	0.00*	0.00*
Members <6 y						
No	0 ^a	0 ^a	1	1		
Yes	0.45 (0.18)	0.34 (0.12)	1.57 (1.09; 2.27)	1.4 (0.56; 2.24)	0.01*	0.01*
Members >65 y						
No	0 ^a	0 ^a	1	1		
Yes	0.04 (0.19)	0.03 (0.17)	1.04 (0.69; 1.46)	1.03 (0.36; 1.7)	0.78	0.88

RO = Romania; PT = Portugal; β = regression coefficient; SE = standard error; OR (95% CI) = odd ratio (95% confidence interval); ^areference value; *the independent variables have a significant effect on the dependent variable at $p < 0.05$.

3.4. Regression analysis of raw-egg based-foods consumption in relation to consumers' demographic profile

The ordinal logistic regression model was used to determine the influence of consumers' socio-demographic profile on the consumption frequency of raw-egg based-foods as shown in Table 7. The educational level was not a significant predictor and thus not presented ($p > 0.05$). The model fit data is presented below:

- The Omnibus test, Pearson and Deviance tests and the test of Parallel Lines revealed that the model had a significant improvement in fit over the null model and that the model fits the data well: Omnibus Test - [$\chi^2(6) = 132.293, p = 0.000$], Pearson Test [$\chi^2(321) = 311.505, p = 0.64$] Deviance Test - [$\chi^2(321) = 251.346, p = 0.99$], Test of Parallel Lines - $p = 0.44$.

The regression model indicated that Romanian and Portuguese men are 1.89, respectively 2.14 times more likely to consume raw-egg based-foods more frequently than women (Table 7). Regarding age, both Romanian and Portuguese consumers aged 16–54 years are up to three times more inclined to consume raw-egg based-foods than those aged >54 years (Table 7). For the consumers from the rural area, the regression indicated odd ratios of 0.62 suggesting that they do not

consume raw-egg based-foods as often as consumers from the urban area, while for the Portuguese consumers the inhabitancy was not a significant variable (Table 7). Families with pregnant women were the strongest predictor with reported odd ratios of 4.03 and 3.19 for Romanian, respectively Portuguese consumers (Table 7). This indicates that families with pregnant women were up to four times more likely to frequently consume raw-egg based-foods than families without pregnant women. The difference between families with and without children is significant as Romanian and Portuguese families who have children (<6 years old) were 1.57, respectively 1.4 times more likely to consume raw-egg based-foods than families without children (Table 7).

Overall, the results from the regression model suggest an increased frequency consumption of raw-egg based-foods and hence a high exposure to food poisoning by men, families with pregnant women and families with children.

Considering the fact that foodborne events were associated with raw-egg based-foods consumption (Table 4) and vulnerable consumer groups are likely to consume them frequently (Table 7), we wanted to check if these consumers mediate the risk of food poisoning by performing food and hand hygiene practices. As such SEM was used to evaluate if vulnerable consumer groups that frequently consume raw-egg based-foods present significant mediation effects on self-reported food and hand hygiene practices.

3.5. EFA

EFA revealed the factor loadings, variance explained by each component, Kaiser-Meyer-Olkin (KMO) coefficient, Bartlett's test of sphericity, as well as the reliability of the data set (Table 7). Due to low factor loadings (<0.3), four items related to egg cleaning were removed. The KMO coefficient was meritorious (0.81) and Bartlett's test of sphericity was significant ($p < 0.001$), indicating that the data was suitable for factor analysis (Tables S1 and S2) (Gaskin, 2016). The factor loadings were >0.4, and the items related just to one component, suggesting both convergent and discriminant validity.

3.6. CFA

CFA was used to confirm the factor structure we extracted in the EFA. The goodness of fit model for the Romanian and Portuguese respondents was acceptable as indicated by the following indices:

- Romanian model: $\chi^2/df = 2.75$, CFI = 0.98, GFI = 0.97, AGFI = 0.94, RMSEA = 0.049, SRMR = 0.039.

- Portuguese model: $\chi^2/df = 2.34$, CFI = 0.96, GFI = 0.96, AGFI = 0.94, RMSEA = 0.048, SRMR = 0.043.

3.7. SEM

Fig. 1 and Fig. 2 show that hypothesis H1 is accepted as SEM revealed a significant **negative** link between consumption frequency of foods prepared with raw eggs and self-reported hygiene practices for Romanian and Portuguese respondents ($\beta = -0.75$; $p < 0.001$, respectively $\beta = -0.70$; $p < 0.001$). This indicates that both the Romanian and Portuguese respondents from this study who frequently consume raw-egg based-foods are less likely to perform food and hand hygiene practices. Hence, the risk of foodborne diseases increases both by consumption of risky foods and by not applying hygiene practices.

The interaction consumption frequency of raw-egg based-foods – families with elderly members (ElderlyMemb_x_ConsFreq) had a significant mediation effect, hence validating hypothesis H2a both for the Romanian and Portuguese respondents ($\beta = 0.31$; $p < 0.001$, respectively $\beta = 0.2$; $p < 0.001$). The finding indicates that families with elderly members **dampened** the negative relationship between consumption frequency of raw-egg based-foods and self-reported hygiene practices.

Foodborne diseases cause harm to all individuals but infants, the elderly, pregnant women, and consumers with compromised immune systems are especially vulnerable (Scott & Herbold, 2010). Contrary to our results it was reported that consumers aged >60 years old are less likely to be aware of the potential harm of risky foods such as raw eggs than consumers aged from 30 to 59 years (Murray et al., 2017). Although elderly consumers (>60 years old) were more prone to follow proper food safety practices than those <60 years old, the majority also reported eating potentially hazardous foods such as soft-boiled eggs or other foods that contain raw eggs (Anderson, Verrill, & Sahyoun, 2011). Similarly, a couple of studies reported an increased prevalence of undercooked eggs consumption with the increase of age, education, and income ($p < 0.001$) (Nesbitt et al., 2009) and lower odds of avoiding raw eggs consumption with the increase of age (Parra et al., 2014). Education had no impact on food safety practices (Parra et al., 2014; Stratev et al., 2017; Katiyo et al., 2019) and was not correlated with risky food consumption as elderly people with a college degree were more likely to consume undercooked eggs, than those who had high school education or less ($p = 0.0294$) (Cates et al., 2009). Elderly consumers (>60 years old) had better self-reported food safety knowledge and practices than younger consumers (<39 years old) (Katiyo et al., 2019) and better observed hygiene practices than parents with at least one child (<10

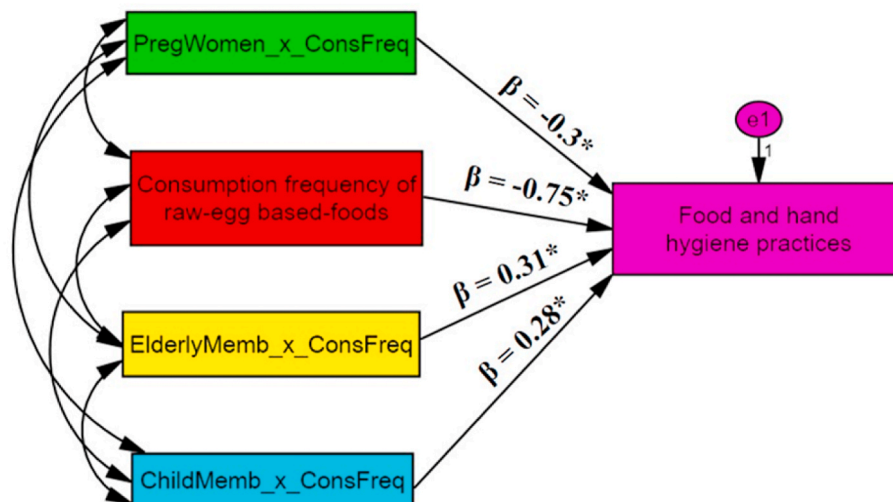


Fig. 1. Structural equation modelling depicting the causal and mediation effects for the Romanian consumers ($p < 0.001$).

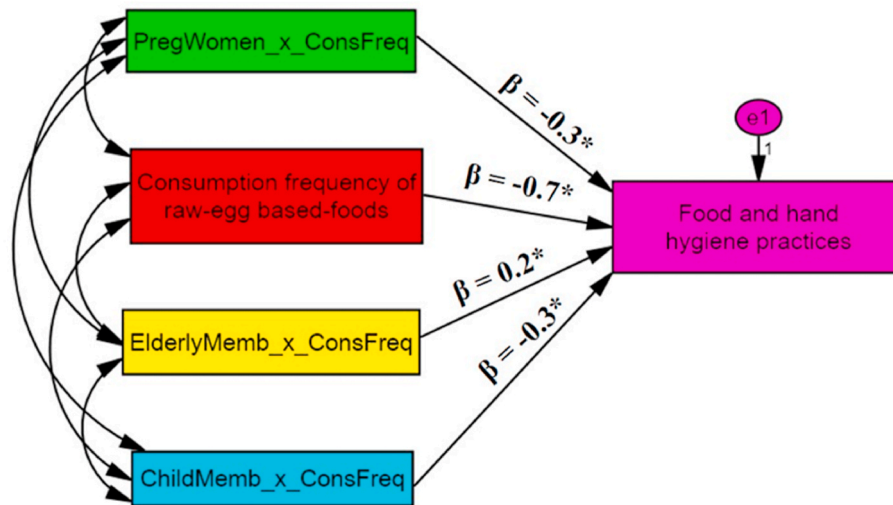


Fig. 2. Structural equation modelling depicting the causal and mediation effects for the Portuguese consumers $^*(p < 0.001)$.

years old) (Hoelzl et al., 2013). However, a recent observational study conducted on 100 elderly consumers (>60 years old) indicated that they frequently engaged in inadequate hand washing practices such as washing hands without soap or using the same towel both for hand and equipment drying (Evans & Redmond, 2019). This correlates with the fact an increased incidence of foodborne diseases was noticed in households consisting of families with elderly members (>60 years old) (Gkana & Nychas, 2018).

The interaction between consumption frequency of raw-egg based-foods – Romanian families with children (ChildMemb_x_ConsFreq) **dampened** the negative relationship between consumption of foods made with raw eggs and self-reported hygiene practices, thus validating hypothesis H2b ($\beta = 0.28$; $p = 0.001$). This indicates that the respondents from this group who frequently eat raw-egg based foods perform food and hand hygiene practices during meal preparation. However, Portuguese families with children **strengthened** the mentioned relationship, hence rejecting hypothesis H2b ($\beta = -0.3$; $p < 0.001$), indicating that they frequently eat raw-egg based-foods and not engage in food and hand hygiene practices.

Among Hispanic families with children (<10 years old), 67%, respectively 70% recognized undercooked eggs, respectively raw eggs as foods likely to cause food poisoning to high-risk groups such as pregnant women, children, and the elderly (Stenger, Ritter-Gooder, Perry, & Albrecht, 2014). Contrary to our results, in a multi-country observational study from Europe, parents with young children were more concerned about the safety of their children rather than paying attention to food safety practices during meal preparation (Skuland et al., 2020).

The interaction consumption frequency of raw-egg based-foods – families with pregnant women (PregMemb_x_ConsFreq) shows that families with pregnant women **strengthened** the negative relationship between consumption frequency of foods with raw eggs and hygiene practices, hence validating hypothesis H2c both for Romanian and Portuguese respondents ($\beta = -0.3$; $p < 0.001$).

Thus, these respondents expose themselves to a high risk of foodborne disease not only by consumption of foods with raw eggs but also due to the lack of food and hand hygiene practices. In the study of Feng and Bruhn (2016) in regards to raw egg consumption and proper hand washing, pregnant women declared: “I have thought about it (cookie dough) with the raw eggs. I do think about it briefly but it doesn’t stop me from licking off my fingers or something.” and “I usually don’t pay attention until the soap is off my hand and that’s it.” Pregnant women were inclined to associate foodborne diseases with improper hygiene practices in restaurants rather than at home (Feng & Bruhn, 2016). Consumers previously reported that they were more concerned in

regards to food produced by others while food prepared at home was perceived at a lower health risk (Bruhn, 2014). However, when pregnant women were video-recorded during meal preparation, they performed hand cleaning practices, mainly due to safety concerns related to their foetus (Skuland et al., 2020).

In order to compare the observed relationships and see if one model presents stronger effects than the other (i.e., the relationship between raw-egg based-foods consumption frequency – food and hand hygiene practices is significantly stronger for Romanian consumers) from both Romanian and Portuguese SEM models we used AMOS and checked for multi-group effects (Gaskin, 2016). However, no significant differences were observed for any of the relationships ($p > 0.05$).

Food safety information sources, as well as the content provided is important, as consumers who were informed about the risks of eating undercooked eggs were less likely to eat them than those who did not receive this information (Nesbitt et al., 2009). Lower awareness on the potential harm of risky foods can contribute to longer and more frequent consumption, thus increasing the susceptibility to food poisoning. However, there were reported cases when consumers who were aware of food safety practices still engaged in unsafe food handling (Mazengia, Fisk, Liao, Huang, & Meschke, 2015; Nesbitt et al., 2009; Patil, Cates, & Morales, 2005; Fein, 2011). Hence, educational campaigns that rely on passive communication of facts and information may not be enough to change consumers’ behaviour (Young et al., 2016) and a multi-faceted approach with consistent over-time efforts is recommended instead for sustainable results (Young et al., 2015).

3.8. Study limitations

The main limitation of this study is that bias can occur for self-reported answers. Consumers may underestimate or overestimate their frequency consumption of raw-egg based-food and the number of foodborne diseases that occurred in their household. Bias also occurs due to social desirability, which is the tendency to respond in ways that makes consumers feel more appropriate or socially acceptable to others (i.e., reporting to wash hands after touching raw meat/eggs).

4. Conclusions

Consumption frequency of raw-egg based-foods and raw egg handling practices were correlated with the foodborne events that occurred in the Romanian and Portuguese respondents’ household in the last year. The regression model indicated a high consumption frequency of raw-egg based-foods both by Romanian and Portuguese men,

consumers aged <55 years, and from the category of vulnerable consumers, families with pregnant women, and families with children, thus exposing themselves to a higher risk of foodborne diseases.

SEM revealed that there is a negative link between consumption frequency of raw-egg based-foods and self-reported food and hand hygiene practices. The mediation effects indicated that Romanian families with elderly members and families with children dampened the negative relationship between consumption of raw-egg based-foods and self-reported hygiene practices, the contrary being observed for Portuguese families with pregnant women and children.

We recommend food safety authorities to adopt multi-faceted approaches with consistent over-time efforts to obtain sustainable results in consumers' food handling practices by exposure to multiple food safety information sources. These approaches involve more than one session or lesson, as well as mass media and social media campaigns that provide food safety materials. Educational materials should highlight the risks of raw eggs and raw egg-products consumption, increase risk awareness of consumers, especially vulnerable groups, and provide specific risk management skills such as cooking food to a safe temperature, hand washing and food handling procedures.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRedit authorship contribution statement

Octavian Augustin Mihalache: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Paula Teixeira:** Formal analysis, Investigation, Writing – review & editing. **Anca Ioana Nicolau:** Methodology, Resources, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration, Supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodcont.2022.109046>.

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