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Kitchen layouts and consumers' food hygiene practices: Ergonomics versus safety

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ABSTRACT

Our paper emphasizes the importance of the kitchen layout in facilitating consumers' food hygiene practices. A significant correlation was found between the sink placement (inside or outside the kitchen) and hygienic practices during food handling based on a survey performed on consumers from ten European countries, indicating that those who had the sink in the kitchen were more likely to perform proper hygiene practices than those who have not. The self-reported practices were supported by observed practices in 64 households from five European countries. The observational study combined with the examination of kitchen layouts revealed that the kitchen work triangle with its apexes represented by the kitchen sink, cooking stove and refrigerator, which is recommended for ergonomic reasons by architects and designers, did not necessarily support food hygiene practices in kitchens. Cross-contamination events were associated with the sink – countertop distances longer than 1 m. Based on this, a new kitchen triangle with its apexes represented by the kitchen sink, working place (usually countertop) and cooking stove, with the distance between the sink and the working place less than 1 m is proposed to be used as norm in kitchen designs for combining ergonomics with safety. This triangle is proposedly named the *food safety triangle* and is aimed to mitigate the risks of foodborne illnesses by creating an arrangement that facilitates hygiene practices. This study is the first to highlight the importance of implementing the concept of food safety in the kitchen design based on significant correlations between kitchen equipment placement and consumers' food safety practices.

1. Introduction

The modern kitchen is the result of two main trends: industrialisation, which started in the nineteenth century, and standardisation, which began in the twentieth century (Beamish, Parrott, Emmel, & Peterson, 2013). Industrialisation joined by democracy and the rising of the middle-class led to servantless homes, which meant that women had new roles and activities to conduct in their homes, cooking being included, while standardisation came, among others, with kitchen layouts that improved work efficiency (Beamish et al., 2013).

In the 1930s, the engineer and motion expert Lillian Moller Gilbreth studied the number of steps required to prepare meals with different kitchen designs and developed the L-shaped kitchen layout (Lange, 2012). This design addressed efficiency between the main three work

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zones, cooking (stove), washing/pre-preparation (sink), and storage (refrigerator), which later became known as the kitchen work triangle (Beamish et al., 2013). In the 1940s, the University of Illinois School of Architecture highlighted the cost reductions by standardized kitchen constructions and was credited with the creation of the **kitchen work triangle** (an imaginary straight line drawn from the center of the sink, to the center of the cooking stove, to the center of the refrigerator and finally back to the sink) (Eiler, 2019).

Nowadays, the concept of work triangle is used as a guideline of kitchen designs and aims to plan out efficient kitchen workspaces with minimal traffic through the work zones (Adams, 2018: Wallender, 2020), similarly with restaurant and industrial kitchen layouts (Pehkonen et al., 2009; Hagan, Kwofie, & Baissie, 2017). According to the National Kitchen and Bath Association (NKBA), each side of the triangle should be between 1.2 and 2.7 m and add up to a total of 4–7.9 m (Beamish et al., 2013). If these work sites are placed too far away from each other, many steps are necessary to move from one work zone to another, which means a lot of time wasted during meal preparation. Meanwhile, if they are too close, the workspace becomes too narrow, making difficult to properly prepare and cook meals (Adams, 2018). With the exception of one-wall kitchens (linear), the work triangle can be applied to all the kitchen layouts such as galleys, L- and U-shaped, L-shaped or linear with island, L-shaped or U-shaped with peninsula. Despite being recommended, the work triangle was laid out for ergonomic reasons and not for safety purposes during food handling and preparation. Additionally, designers' advice and consumers' priorities are mostly aimed at the kitchen arrangement trends, appliances design and functionality rather than food safety considerations (Petrova, 2018). Since the domestic environment is one of the most common sources of foodborne outbreaks (Al-Sakkaf, 2015; EFSA & ECDC, 2021; Langiano et al., 2012; Wu et al., 2018), a design that would increase the frequency of the cleaning actions for hands, cutting boards, knives etc. could reduce the number of cross-contamination (CC) events during meal preparation and minimise the risk of foodborne illness.

Hence, the objectives of the study were:

- To assess through a survey conducted in ten European countries the correlation between consumers' food safety and hygiene self-reported practices and the sink placement in the household (wash site for kitchen related activities);
- To determine whether there are correlations between the hand hygiene practices and kitchen designs based on home visits conducted in five European countries during the preparation of a chicken and salad meal;
- To suggest a kitchen layout that facilitates hygienic practices. Thus, we intend to draw attention to a kitchen organisation focusing on food safety, which has as focal point the placement of the sink against the preparation area. Our proposal is to consider a triangle with apexes represented by the countertop or table (preparation area where food and utensils are handled), the sink (washing area) and the stove (cooking area). Hence, we have raised the hypothesis that a short distance between the preparation area and the washing area could favour higher hand washing frequencies, which in turn will reduce the risk of cross-contamination and food poisoning.

2. Materials and methods

This study is a multidisciplinary approach and combines a quantitative consumer survey with qualitative consumer household visits. Through a food safety-based survey we assessed potential correlation between consumers' self-reported hygienic practices during food handling and sink placement in the kitchen layout, while by household visits including live video-recordings we were able to evaluate a potential connection between the kitchen design and the number of observed practices that could lead to cross-contamination during meal preparation. Both the survey and the visits were performed in the framework of the SafeConsume project (Horizon 2020; grant agreement No 727580, http://safeconsume.eu/), which aims to improve consumers' food safety behaviour through effective tools and products, communication strategies, and education.

2.1. Quantitative method

2.1.1. Data collection

Data were collected via a web-based survey. The questions addressed in the present study were part of a larger consumer survey that was sent to consumers from 10 European countries (Denmark, France, Germany, Greece, Hungary, Norway, Portugal, Romania, Spain, and the UK). The survey was discussed and approved by microbiologists, sociologists, and specialists involved in food safety and consumers' behaviour. The questionnaire was conducted between December 2018 and April 2019. The sample was stratified based on the regions of the participating countries that represent the NUTS II-level divisions both for the European Union and non-European Union member states and the education level of the respondents (Langsrud et al., 2020).

2.1.2. Survey design and reliability

To evaluate consumers' hygienic practices the following questions were asked: "How likely is it that you would clean your hands immediately after touching raw chicken?", "After cutting chicken, how likely is it that you will re-use the same cutting board (without washing it) for vegetables, salads or fruits?", and "After cutting chicken, how likely is it that you will re-use the same knife (without washing it) for vegetables, salads or fruits?" (ordinal scale, 1 - no chance or almost no chance; 6 – fairly good possibility; 11 – certain or practically certain). A question regarding the placement of the sink (nominal scale, yes/no; in kitchen or outside the kitchen) was included to assert if there are correlations between food handling practices and the washing site. A total of 9966 surveys were returned for sink placements and 7866 for food hygiene practices. The questionnaire had a reliable internal consistency (Cronbach's alpha = 0.74).

2.2. Qualitative method

2.2.1. Household visits and video-recording

A part of the SafeConsume's transdisciplinary fieldwork aimed to trace and describe food safety and hygiene practices and pinpoint cultural differences between households from Norway, France, Romania, Portugal, and Hungary. In the present study, 64 households were included, covering three categories of consumers: young single men (YSM), which are seen as high-risk takers, young families (YF) with either pregnant women or children <5 years old, and elderly consumers (>65 years old) (EP) both being part of vulnerable groups. The households were selected both from urban (U) and rural (R) areas. All consumers signed an informed consent form. Ethical approvals for the study were granted by the Norwegian Centre for Research Data (Norway, 55256/3/AMS), Commission Nationale de l'Informatique et des Libertés (France, 152182 REC 0717 T001), the Ethical commission of the Dunarea de Jos University of Galati (Romania, RCF1548/31.08.2017), the National Data Protection Commission (Portugal, 13914/2017), and the National Food Chain Safety Office (Hungary). The kitchen visiting teams consisted of food safety microbiologists, and sociologists with the exception of Hungary, where teams were built with students in veterinary medicine. The teams' members observed consumers throughout the food shopping – cooking chain and documented each step of consumers' journey. As a result, video-recording analysis and kitchen drawings were made for households from Norway (13), France (15), Romania (15), Portugal (13), and Hungary (8).

The approach and recording methods used the "go-along" technique, where the participants take control and lead the activity, while the interviewers (i.e., researchers) accompany the participant in their own familiar environments, which in this case was the kitchen (Carpiano,

2009; Kusenbach, 2003) with minimal interference in their daily routine.

Video-recording during meal preparation allowed access to consumer hygiene practices, while also observing the layout of kitchens and work areas. The videos were analysed with the Noldus Observer XT software (Noldus Information Technology, Wageningen, Netherlands). In Observer XT, data analysis is based on viewing the event log that contains the actions performed by the consumers from one or more videos streams. By analysing the records, we determined the frequency of hand cleaning actions during food handling and preparation, as well as practices that could potentially lead to cross-contamination.

2.2.2. Kitchen layouts

The members of the research groups of each country provided the necessary information regarding the placement of equipment and dimensions of the rooms based on the preliminary drawings of kitchen layouts made during the household visits. The standard dimensions for the main kitchen equipment and work sites were taken into consideration from a database of dimensioned drawings, which also has dimensions guides for kitchen appliances (https://www..guide/dimensions). Final layouts of the visited kitchens were drawn using AutoCAD 15 software (Autodesk Inc., San Rafael, CA) and presented in *Data in Brief* (Mihalache et al., submitted). The software enables the user to draw with fractional dimensions and to define precisions to any number of decimal places, which is not achievable in hand-drafted drawings, thus leading to accurate drawings in regard to all dimensions. This allowed us to calculate the length of sides and perimeter of two type of triangles: the working triangle **(sink – stove – refrigerator)**, and the food safety triangle (**sink – countertop - stove)**.

After this step, we analysed possible connections between the pattern of arrangement of the kitchen equipment and actions performed by consumers after touching raw food, which led to cross-contamination events (e.g., not washing hands or wiping hands with a dish cloth instead of washing hands followed by answering phone, opening food containers, cupboard drawers and doors, touching fridge handle and drawers, and touching animate surfaces like their face and mouth or children's hands and face).

2.3. Statistical analysis and kitchen layouts measurements

The normality of the data was assessed using the Shapiro-Wilk test. The test indicated that the data from the survey is not normally distributed ($p < 0.05$).

Spearman's rank correlation coefficient (ρ) and regresion analyses were calculated with SPSS Statistics 26 (IBM Software Group, Chicago, IL).

Spearman correlations were performed with the data obtained from the questionnaire to evaluate the connection between consumers' food hygiene practices and sink placement in the kitchen layout (significant at $p < 0.05$). Ordinal regressions were applied to determine if the sinks placement had significant effects on consumers' self-reported food hygiene practices (i.e., if consumers who have a sink-equipped kitchen are more likely to engage in safe food handling than consumers who do not own a sink-equipped kitchen). The predictors from the regression models were assessed using the Omnibus test. The goodness fit of the models was assessed with the Pearson and Deviance tests. Non-significant coefficients imply the model fits the data well (Field, 2018). The assumption of proportional odds or the parallel lines test indicates that the same set of coefficients is present across different response levels (assumption accepted if $p > 0.05$). If this assumption is satisfied it indicates that the use of regression analysis is adequate ($p > 0.05$) (Osborne, 2017).

Bootstrapping with 1000 iterations was used both for the correlation and regression analyses to obtain bias-corrected and accelerated (BCa) bootstrap intervals (95% confidence interval). This method corrects for bias and provides unbiased p-values (Field, 2013).

The results from the household visits were analysed using ordinal regressions and the number of cross-contamination events was depicted as a Sankey diagram using Tableau Software 2020.1 (Salesforce, Seattle, WA).

3. Results and discussions

3.1. The demographic profile of the groups participating in the study

3.1.1. Survey respondents

The demographic profile of the consumers from 10 European countries is shown in Supplementary file S1.

The survey respondents were females in a proportion of 50.5%. Regarding respondents' age, 18.6% were 35–44 years old and 18.6% were 65–75 years old. Half of them had a high level of education (54.4%), and almost half lived in a city (44%).

3.1.2. Visited consumers

Demographic details about the visited consumers are presented in the accompanying *Data in Brief* manuscript (Mihalache et al., submitted). From the visited consumers, 57.8% were from the urban area and 42.2% from the rural area. Regarding the category of consumers, 34.3% were young families (YF), 39% elderly people (EP), and 26.7% young single men (YSM). The data describing the consumers' kitchens (kitchen areas, perimeters' length and sides' lengths of triangles taken into discussion in this study) are also provided in the accompanying *Data in Brief* manuscript (Mihalache et al., submitted). Each household was assigned a unique identifier which has the following format: country abbreviation ALPHA-2 (ISO-3166-1)_consumer pseudonym_category of consumer (EP, YF, YSM). The process of attributing pseudonyms to the visited consumers is described by Skuland et al. (2020).

3.2. Consumers' self-reported hygienic practices and the placement of the sink

Based on the self-reported data in the survey, we calculated the correlations between consumers' food hygiene practices and sink placement. From the total number of respondents, 1285 (15%) had their sinks placed outside the kitchen.

Spearman correlations (ρ) were performed to assess a preliminary connection between sink placement and consumer's self-reported food hygiene practices. A significant negative correlation was found between sink placement (outside of kitchen) and probability of washing hands after touching raw chicken, which indicates that consumers who do not own a sink-equipped kitchen are less likely to wash their hands than consumers owning a sink-equipped kitchen ($\rho = -0.12$; $p < 0.001$; BCa 95% CI: −0.07; −0.16). Additionally, the significant positive correlations between sink placement outside the cooking area and the practice of re-using the same cutting board ($\rho = 0.11$, $p < 0.001$; BCa 95% CI: 0.06; 0.13) or knife ($\rho = 0.14$, $p < 0.001$; BCa 95% CI: 0.08; 0.2) without cleaning them, suggested once again that the kitchen layout influences consumers' food safety practices during food handling.

A couple of studies indicated that the frequency of pathogen ingestion increases because of the contamination of RTE foods (from raw meals via unwashed cutting boards, knives and the cook's hands), and due to the increased frequency of contact between hand – unwashed utensils during food handling (Kennedy et al., 2011; Zhu et al., 2017). The kitchen counter and cutting board were found to be among the most contaminated surfaces in the kitchen with *E. coli* ($>10^3$ CFU/swab) (Azevedo, Albano, Silva, & Teixeira, 2014).

Table 1 displays the results from the regression models. Ordinal regression was applied to determine how much of the variability in hygienic practices during cooking could be explained by the layout of the kitchen and more precisely by the location of the sink inside or outside the kitchen. The goodness-of-fit tests for Table 1 are presented in Supplementary file S2.

Table 1
Regression analysis of the self-reported hygienic practices during food handling dependent on the sink placement either inside or outside the kitchen.

	Model	Sink placement	β (SE)	BCa (95% CI)	OR (95% CI)	p
How likely is it that you would clean your hands immediately after touching raw chicken? *	1	Inside Outside	0[a] −0.64 (0.03)	 −0.32; −0.89	1 0.52 (0.44; 0.61)	0.00**
*After cutting chicken, how likely is it that you will re-use the same cutting board for vegetables, salads or fruit?**	2	Inside Outside	0[a] 0.37 (0.08)	 0.19; 0.54	1 1.5 (1.23; 1.71)	0.00**
*After cutting chicken, how likely is it that you will re-use the same knife (without washing it) for vegetables, salads or fruit?**	3	Inside Outside	0[a] 0.56 (0.08)	 0.25; 0.86	1 1.8 (1.48; 2.07)	0.00**

β = regression coefficient; SE = standard error; BCa (95% CI) = Bias-corrected accelerated (95% confidence interval) using the bootstrapping technique (1000 iterations); OR (95% C.I.) = odds ratio (95% confidence interval); a = reference value; *N = 7866 valid answers; **$p < 0.01$.

Sink placement was a negative predictor as consumers who had the sink placed outside the kitchen were less inclined to wash their hands after touching raw chicken than consumers who had their sinks in the kitchen (Table 1).

The placement of the sink also indicated that consumers who have sinks outside the kitchen are 1.5–1.8 times more likely to re-use the same cutting board and/or knife without washing them after cutting raw chicken for the preparation of vegetables, fruits or salad than consumers who have sink-equipped kitchens (Table 1).

Overall, the regression analysis of the survey showed that the placement of the sink outside the kitchen was strongly associated with lower frequency of practices that can reduce cross-contamination.

3.3. Observed food hygiene practices and main cross-contamination events that took place in the kitchens during the SafeConsume visits

By using the "go-along" technique during visits, we obtained raw live footage of consumers hygienic practices, unlike CCTV recordings, where participants turn on still cameras when they prepare food leading to "participant-produced" footage (Kendall, Brennan, Seal, Ladha, & Kuznesof, 2016; Muir & Mason, 2012). The main assumption of this technique is that the interviewers can better understand how people appreciate and get involved in their physical and social environments (Kusenbach, 2003). Having the participants taking the lead reduces the feeling of intrusion (Kendall et al., 2016) and gives them more freedom in follow-up discussions and interviews (Martens, 2012; Sweetman, 2009).

In Fig. 1, the main potential cross-contamination events and the occasion they occurred are presented. The events were counted as actions which involved participants handling food and then manipulating other kitchen items or foods without washing hands in between the actions. The most frequent actions after touching raw foods (raw chicken, raw vegetables, lettuce) included opening drawers or the fridge, manipulating food containers, checking/answering the phone and inefficient hand cleaning such as wiping with a dish cloth instead of applying the recommended washing procedure with water and soap. The other potential cross-contamination events consisted of consecutive handling of different types of food without applying a hand cleaning procedure such as: handling washed vegetables that will be eaten raw after touching unwashed lettuce and/or raw chicken, handling washed lettuce after touching raw unwashed vegetables and/or raw chicken, proving that consumers were not aware on the key moments when it is important to apply hygienic practices. There were also cases when the consumers touched their face or interacted with their children right after handling raw foods and without washing their hands.

Previous studies reported that *E. coli* was found on the surface of cell phones, thus presenting a health concern due to the high frequency of hand-phone contact during meal preparation and while eating (Her, Seo, Choi, Pool, & Ilic, 2017, 2019). The fact that the visited consumers manipulated risky foods without properly washing their hands increased the risks of foodborne illnesses. Several outbreaks underlined the importance of RTE vegetables and salads as foodborne vehicles for pathogens such as *E. coli*, *Salmonella*, and *L. monocytogenes* (Bae, Seo, Zhang, & Wang, 2013; Castro-Rosas et al., 2012; Lokerse, Maslowska-Corker, van de Wardt, & Wijtzes, 2016).

Table 2 displays the number of cross-contamination events that occurred in each country (alphabetically ordered) and the occasion they occurred. The highest average number (21) of potential cross-contamination events was recorded during handling of vegetables (tomatoes, cucumbers, onions etc), and the lowest during the preparation of lettuce salad (15) and raw chicken (15) (Table 2). A comparison between countries revealed that Romania and Hungary registered the highest average number of potential cross-contamination events.

3.4. Correlations between food hygiene practices during food preparation and kitchen designs

We observed a similar average number of cross-contamination actions in kitchens where the work triangle complied with the recommended perimeter of 4–7.9 m and in kitchens where the perimeter was higher than 7.9 m (Table 3). Out of the 51 households where the arrangement of the equipment followed the kitchen work triangle recommendations, 8 had the key equipment placed in line (particular case of the work triangle, in which the tips of the triangle are arranged in line). Examples of kitchens where the work triangle had the recommended value for its perimeter are presented in Fig. 2a and b and examples of kitchens where the recommended value for the work triangle is exceeded as result of placing one of the equipment outside the kitchen are presented in Fig. 2c and d.

The practices of the consumers where the perimeter of the work triangle was exceeded can be explained by the fact that those who had equipment placed in other rooms resorted to solutions that favored the practice of correct actions (e.g., bringing a washing basin with water on the countertop, bringing the ingredients from the refrigerator before starting cooking and placing them on the countertop) although in some cases these solutions generated other incorrect actions (e.g., washing hands in the water where chicken meat has been washed or rinsing hands in the same water for several times). It is interesting to notice that some consumers living in flats, due to lack of space, extend their kitchens in their balcony where they place either the stove alone or the stove and the sink (RO_Bogdan_YSM, RO_Florinel_YSM). See their kitchen layouts in *Data in Brief* (Mihalache et al., submitted).

To further analyse if the work triangle influences consumers' food hygiene and safety practices, we investigated if there are any significant correlations between the recommended dimensions of each side of the triangle (1.2–2.7 m) and the number of potential cross-contamination events. Supplementary file S3 shows the correlations between the dimensions of the work triangle's sides and the number of cross-

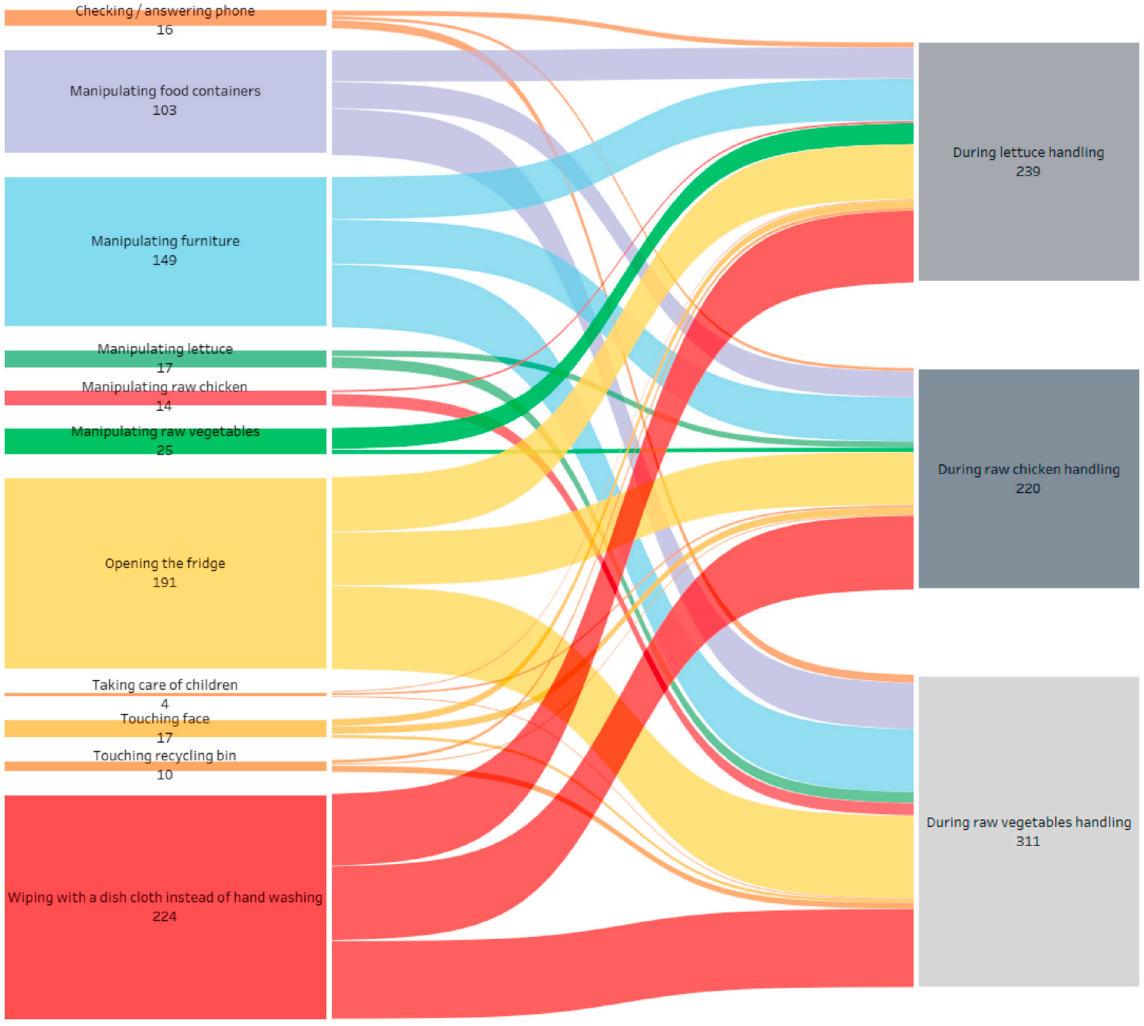

Fig. 1. Sankey diagram illustrating the main potential cross-contamination events and the occasion they occurred.

Table 2
Average number of potential cross-contamination events per country and per kitchen and the occasion they occurred.

	Average number of CC events that occurred during handling of…			
Country	**raw chicken**	**raw vegetables**	**lettuce**	**Total**
France	3	3	3	9
Hungary	6	3	3	12
Norway	1	6	2	9
Portugal	2	3	4	9
Romania	3	6	3	12

Legend: Average number of CC events — ≤ 5 | 5-10 | > 10

Table 3
Average number of potential cross-contamination events and the occasion they occurred in kitchens where the arrangement of the key equipment had the recommended perimeter of the work triangle (4–7.9 m) and kitchens where the arrangement of the equipment had a perimeter >7.9 m.

		Average number of CC events that occurred during handling of…			
Kitchen work triangle perimeter, m	n	raw chicken	raw vegetables	lettuce	Total
4-7.9	51	3	4	3	10
>7.9	13	4	5	2	11

Legend: Average number of CC events — ≤ 5 | 5-10 | > 10

contamination events. We found no significant correlations between the dimension of each side of the work triangle (even when the recommendations are respected) and the average number of cross-contamination events. Hence, we can conclude that from the 64 visited households the kitchen work triangle was not associated with consumers' food hygiene practices.

The kitchen work triangle is considered by some kitchen designers outdated and hard to set up because of the space required, especially in Galley-shaped kitchens, and because the design is inflexible and confining (Williams, 2020; Camp, 2017). Even the world-renowned chef from the 1960s, Julia Child, stated that she does not pay too much attention to the kitchen work triangle arrangement (Heyne, 2016). The split opinions among kitchen architects and designers revolve around the fact that when they design a kitchen, they use the work triangle both as a starting point and as a checkpoint because they consider it a standard in the design industry that facilitates meal preparation (Williams, 2020). However, other designers stated that the human motions in the kitchen are far too individual and diverse to benefit from the purpose (efficiency) of the kitchen work triangle (Camp, 2017).

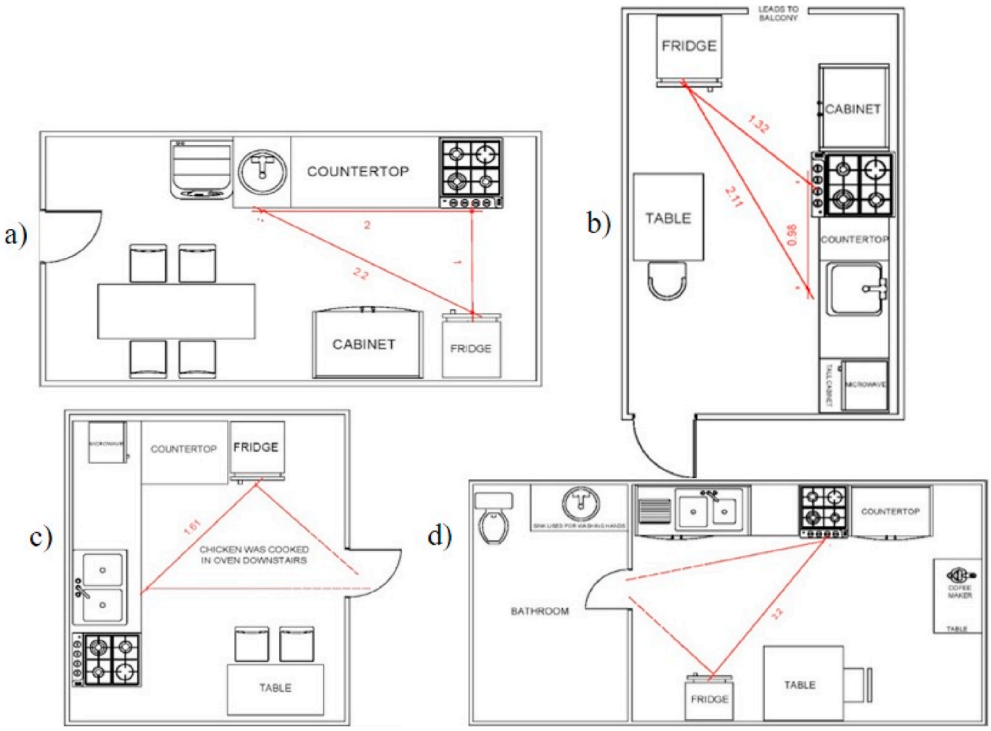

Fig. 2. a) and b) Kitchen layouts (RO_Amalia_YF and PT_Augusto_EP), where the work triangle has the recommended perimeter (4–7.9 m); c) and d) Kitchen layouts (NO_Fredrik_YSM and FR_Vincent_YSM) where one of the equipment was outside the kitchen, hence the recommended perimeter was exceeded.

3.5. Placement of the washing area (sink) and correlation with consumers observed hygiene practices

The regression analysis between the placement of the sink and consumers' self-reported hygienic practices revealed a relationship that is also supported by the results from the observational studies. Table 4 shows consumers' hand cleaning actions and potential contamination events from the households visited by the SafeConsume teams in relation with the sink placement. The goodness-of-fit tests for Table 4 are presented in Supplementary file S2.

Sink placement was a strong significant predictor of consumers' hand cleaning actions and as well of the potential cross-contamination events. Consumers who had a sink inside their kitchen were 2.25 times more likely to wash their hands with soap and water than those who did not have a sink-equipped kitchen. Regarding hand rinsing events, the difference between consumers who had the sink inside or outside the kitchen is significant. Those who had a sink inside their kitchen were 5 times more inclined to rinse their hands during food handling than those who had the sink outside their kitchen. The sink placement also indicated that cross-contamination events are less likely to occur when the sink is placed inside the kitchen.

Kitchens with no sink were present in Romanian rural old houses (5 households) and in one Norwegian household. An example of sink placed outdoors in a Romanian rural household is presented in Supplementary file S4.

Although sinks were placed in kitchens in all the other households, there were four situations, two in Norway, one in Romania and one in France, in which consumers did not use kitchen sinks for washing hands but preferred to use the bath sink for different reasons. Our calculations took this situation into consideration. In Romania, although the situation seemed to be at the first glance circumstantial for the kitchen RO_Sorina_YF (a sink full of unwashed dishes), it proved to be permanent (a sink designed for bathrooms was mounted in the kitchen and a table nearby was used to keep a dish rack; the lady of the house told the researchers that she decided to have just hot water in the kitchen following an incident related to a damaged pipe whose replacement would have necessitated floor destruction; the water was really hot - about 65 °C; cold water was carried from the bathroom in a plastic basin to be used for washing lettuce, vegetables and chicken meat, while washing hands was performed in the bathroom). See this sink in Supplementary file S4.

In households where the sink was placed outside the kitchen, the consumers performed 1–2 hand washing actions and 1–5 rinsing actions during cooking, while one of the consumers only wiped his hands with a dish cloth (4 times) instead of washing hands. Higher frequencies in hand washing and rinsing were observed for those who had sinks in their kitchens (up to 5 hand washing and 11 rinsing actions per consumer), proving the significance of the sink placement in the kitchen.

Table 4
Regression analysis of the observed hand cleaning actions and cross-contamination events in relation with the placement of sink either inside or outside the kitchen.

	Model	Sink placement	β (SE)	BCa (95% CI)	OR (95% CI)	p
*Hand washing events**	1	Inside	0.81 (0.07)	0.44; 1.17	2.25 (1.93; 2.63)	0.00**
		Outside	0[a]		1	
*Hand rinsing events**	2	Inside	1.71 (0.47)	0.92; 2.39	5.54 (0.11; 31.05)	0.00**
		Outside	0[a]		1	
*Cross-contamination events**	3	Inside	−0.35 (0.08)	0.45; 0.63	0.7 (0.58; 0.82)	0.00**
		Outside	0[a]		1	

β = regression coefficient; SE = standard error; BCa (95% CI) = Bias-corrected accelerated (95% confidence interval) using the bootstrapping technique (1000 iterations); OR (95% CI) = odds ratio (95% confidence interval); a = reference value; *N = 64 participants; **$p < 0.01$;

As discussed in a separate publication, besides sink placement, the other factors that influenced consumers' hand washing frequencies included their level of knowledge, routines, and risk perception (Didier et al., 2021).

3.6. An approach to a food safety kitchen design

As shown in section 3.4 the kitchen work triangle was not associated with proper food safety practices. Therefore, we propose a new concept, the **food safety triangle**, represented by the kitchen sink, working place (usually countertop) and cooking stove. In the food safety triangle, one apex was considered either the countertop or the table depending on the place where the consumers prepared the meal. Most of the consumers used the surface of a cabinet (countertop) while in other cases the kitchen table alone was the place where consumers prepared food. In comparison with the work triangle, for the food safety triangle we have considered the preparation area (countertop or table) instead of the cold storage area (refrigerator), as this is the place where most of the meal preparation is done and requires more hand cleaning actions to avoid cross-contamination events. The cold storage zone was excluded from the triangle because consumers can take out of the fridge all the ingredients they need for cooking and place them near the preparation area right before they start preparing a meal. Then, when meals are ready, food needs to cool before being introduced into the fridge. So, we considered from a safety standpoint that there is a minimal interaction with the fridge during cooking *per se*, if consumers are well organized for the meal preparation, leading to a low incidence of contamination events between fridge and the other surfaces.

Table 5 presents the average number of potential contamination events and when they occurred in kitchens where the arrangement of the key equipment had a perimeter ≤4 m and kitchens where the arrangement of the equipment had a perimeter >4 m.

The average perimeter of the food safety triangle from the visited households was 4 m, and we chose to compare the number of cross-contamination actions between kitchens where the perimeter was ≤4 m (37 households) and >4 m (27 households). Two more cross-contamination actions per household were noticed in kitchens with the perimeter >4 m than in kitchens with the perimeter ≤4 m (Table 5). In our calculations, we considered the distance sink-working place-stove even for kitchens where the key equipment was placed in line (26 kitchens). Other comparisons that were tested involved perimeters from ≤2 to >8 m but no significant differences were found regarding the number of potential cross-contamination events ($p > 0.05$).

To better understand if there is a relationship between consumers' observed contamination actions and the areas of the food safety triangle, we analysed how the number of cross-contamination events is predicted by: a) the sink – countertop distance, b) the perimeter of the food safety triangle, and c) the interaction sink – countertop distance + the perimeter of the food safety triangle (Table 6). The goodness-of-fit tests for Table 6 are presented in supplementary file S2.

Table 5
Average number of potential contamination actions and the occasion they occurred in kitchens where the arrangement of the key equipment had a perimeter ≤4 and kitchens where the arrangement of the equipment had a perimeter >4 m.

		Average number of CC events that occurred during handling of…			
Food safety triangle perimeter, m	n	raw chicken	raw vegetables	lettuce	Total
≤4	37	2	4	3	9
>4	27	4	4	3	11

Legend: Average number of CC events — ≤ 5 | 5-10 | > 10

Examples of kitchens from the visited consumers where the food safety triangle had a perimeter ≤4 m and the sink – countertop distance was ≤1 m are shown in Fig. 3a and b, while in 3c and 3d there are examples of a food safety triangle arrangement with the perimeter >4 m and sink – countertop distance >1 m.

Table 6
Regression analysis of the observed cross-contamination events in relation to the sink - countertop distance, the perimeter of the food safety triangle, and the interaction sink – countertop distance + the perimeter of the food safety triangle.

Model 1	*Cross-contamination events*			
	β (SE)	BCa (95% CI)	OR (95% CI)	p
Sink – countertop distance, m*				
≤1	0[a]		1	
>1	2.25 (0.5)	0.39; 1.88	9.51 (3.14; 28.78)	0.00**
Food safety triangle perimeter, m*				
≤4	0[a]		1	
>4	1.11 (0.05)	0.03; 2.32	3.03 (1.13; 8.09)	0.03***
Interaction of sink – countertop distance with food safety triangle perimeter, m*				
Sink-countertop ≤1 and safety triangle ≤4	0[a]		1	
Sink-countertop >1 and safety triangle >4	0.77 (0.03)	0.19; 1.55	2.15 (1.25; 3.7)	0.00**
Sink-countertop >1 and safety triangle ≤4	0.64 (0.04)	0.37; 1.01	2.08 (0.91; 4.72)	0.00**
Sink-countertop ≤1 and safety triangle >4	−0.37 (0.03)	−0.52; −0.24	0.69 (0.33; 1.44)	0.02***

β = regression coefficient; SE = standard error; BCa (95% CI) = Bias-corrected accelerated (95% confidence interval) using the bootstrapping technique (1000 iterations); OR (95% CI) = odds ratio (95% confidence interval); a = reference value; *N = 64 participants; **$p < 0.01$; ***$p < 0.05$.

As shown in Table 6, the number of contamination events was influenced by the sink – countertop distance. Thus, in kitchens where the distance sink – countertop was >1 m the probability of cross-contamination events occurring was nine times higher than when the sink – countertop distance was ≤1 m, indicating that the number of cross-contamination actions carried out by the consumers visited by the SafeConsume teams increased especially when the sink – countertop distance was >1 m. This area placed near the sink, either represented by a countertop or a table and named preparation area across the manuscript, should be dedicated to raw food handling. Ready-to-eat foods should have their places in the kitchen, different than the preparation area, to avoid cross-contamination as the sink itself and the washing procedures may spread microorganisms to nearby surfaces.

Another aspect related to the number of practices leading to cross-contamination while preparing a chicken and salad menu is underlined by the size of the perimeter of the food safety triangle. The perimeter was a significant predictor of potential cross-contamination events. When the perimeter was >4 m consumers were three times more likely to perform actions that could lead to cross-contamination.

When the sink – countertop distance is > 1 m and the perimeter of the food safety triangle is > 4 m, cross-contamination events are two times more likely to occur. Even when the perimeter is ≤ 4 m, if the sink – countertop distance is > 1 m there is still a positive relation with the cross-contamination events. However, when the sink – countertop distance is ≤ 1 m and the perimeter is > 4 m cross-contamination events are less likely to take place, implying a potential connection between consumers' observed hygiene practices and sink – countertop distance. Thus, the higher the perimeter of the food safety triangle and the sink – countertop distance, the higher the number of cross-contamination events that took place in the consumers' households.

However, it should be underlined that the ordinal regression model 1 applies to 40% (R^2) of the experimental data due to the high heterogeneity of the household visited ranging from the ones without minimal means for ensuring food safety (i.e., kitchens without running water,

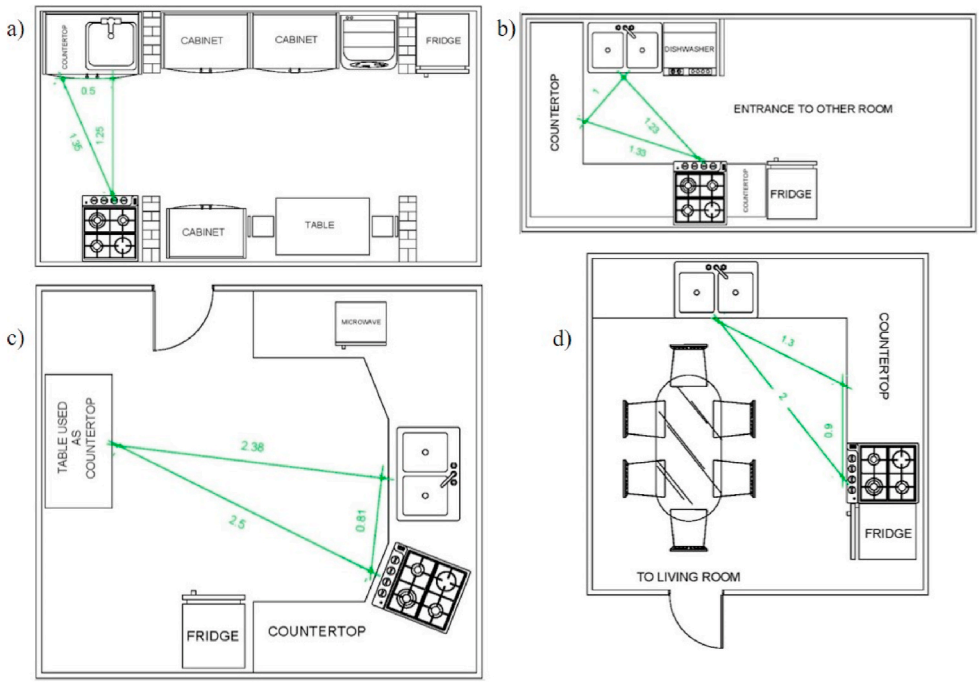

Fig. 3. a) and b) Kitchen equipment arrangement where the food safety triangle has a perimeter ≤4 m and a sink – countertop distance ≤1 m (RO_Ionel_YSM and NO_Inger_EP); c) and d) Kitchen equipment arrangement where the food safety triangle has a perimeter >4 m and a sink – countertop distance >1 m (HU_BA_YF and FR_Elodie_YF).

kitchens with no warm water tap) to the very modern ones benefiting from sophisticated household appliances. It should also be noted that observational studies, in comparison with designed experiments, are more difficult to be calibrated and could present higher experimental errors as their results might reflect a number of potentially confounding factors (Table 6).

In Table 7 is displayed the average number of potential cross-contamination events, the occasion they occurred, and the sink – countertop distance. In 34 kitchens, the sink – countertop distance was ≤1 m and the average number of potential contamination actions was 8, while in the other 30 kitchens the sink – countertop distance was >1 m and the average number of potential contamination actions was 12.

During the household visits we observed 14 cases where consumers had a countertop near their sink (≤1 m) but chose to prepare the meal either on the kitchen table or on another countertop instead (placed at >1 m away from the sink). For these consumers the average number of potential cross-contamination events was 10, higher than the average when the sink – countertop distance was ≤1 m (e.g., FR_Mathilde_YF, NO_Nils_EP, RO_Balanel_YSM, HU_Margo_EP). More details about their kitchen layouts are shown in *Data in Brief* (Mihalache et al., submitted). To such consumers it is necessary to explain the importance of the placement of the countertop near the sink.

Table 7
Average number of potential contamination actions related to the sink – countertop distance and the occasion they occurred.

	Average number of CC events that occurred during handling of…			
Sink - countertop distance, m	n	raw chicken	raw vegetables	lettuce	Total
≤1 m	34	2	4	2	8
>1 m	30	4	5	3	12

Legend: Average number of CC events: ≤ 5; 5-10; > 10

For food safety reasons, the distance between sink and preparation area (countertop or table) is more important in the kitchen design than the work triangle.

By highlighting the importance of kitchen layouts on consumers' food safety practices related to cross-contamination events we hope that new recommendations will be made prioritising consumer's safety and not only efficiency in kitchens.

This is a new suggested concept and although in this study we presented data that supports our concept, we acknowledge there are limitations such as: a) the sample size (64 households), b) other factors that could cause cross-contamination events (consumers' level of knowledge, routines, and foodborne risk perception), c) outliers (consumers lacking basic means), and d) consumers' behaviour that can change under observation (Evans & Redmond, 2018). Our results can be used as a starting point for future research regarding kitchen arrangements supporting minimisation of cross-contamination events.

4. Conclusions

Our study, which to our knowledge is the first showing real kitchen layouts from five European countries, emphasizes the importance of these layouts in relation to consumers' hygiene practices.

The findings from the visits support the fact that a significant correlation exists between the sink placement (inside or outside the kitchen) and hygienic practices during food handling, which was the finding from the survey, and, more than this, showed that the kitchen work triangle was not associated with food safety, since the number of food hygiene practices was not correlated with the recommendations for the work triangle.

This study outlines the importance of implementing the concept of food safety in kitchens highlighting significant correlations between the sink placement and consumers' food hygiene practices. The regression models for consumers' observed food hygiene practices indicated that cross-contamination events are more likely to occur when the sink – countertop distance is > 1 m and the perimeter of the safety triangle is > 4 m. Hence, we consider that the food safety triangle, which is the

triangle formed by the apexes of sink – countertop – stove that we suggest in this paper as replacement of the kitchen work triangle, with the perimeter ≤4 m and its side represented by the sink – countertop distance ≤1 m may be an acceptable compromise between safety and efficiency in kitchens.

As our study was observational, examined kitchens that highly differed in the way they were designed and equipped and took into consideration just the number of potential cross-contamination events and not the severity of the associated risks, it opens the floor for studies to confirm our theory.

Meanwhile, education of consumers should not be neglected. As kitchen designs favouring hygienic practices is a necessary but not sufficient condition to reduce risk, making consumers aware on the key moments when they have to clean their hands, utensils and surfaces remains a challenge for assuring food safety in homes. Consumers able to apply good hygiene practices in their kitchens and a kitchen organisation facilitating these good practices may be a synergistic approach to reduce foodborne illnesses.

CRediT authorship contribution statement

Octavian Augustin Mihalache: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Trond Møretrø:** Formal analysis, Investigation, Writing – review & editing. **Daniela Borda:** Formal analysis, Investigation, Writing – review & editing. **Loredana Dumitrascu:** Formal analysis, Investigation, Writing – review & editing. **Corina Neagu:** Formal analysis, Investigation. **Christophe Nguyen-The:** Formal analysis, Investigation, Writing – review & editing. **Isabelle Maitre:** Formal analysis, Investigation. **Pierrine Didier:** Formal analysis, Investigation. **Paula Teixeira:** Formal analysis, Investigation, Writing – review & editing. **Luis Orlando Lopes Junqueira:** Formal analysis, Investigation, Writing – review & editing. **Monica Truninger:** Formal analysis, Investigation. **Tekla Izsó:** Formal analysis, Investigation. **Gyula Kasza:** Formal analysis, Investigation. **Silje Elisabeth Skuland:** Formal analysis, Investigation. **Solveig Langsrud:** Formal analysis, Investigation, Writing – review & editing. **Anca Ioana Nicolau:** Conceptualization, Methodology, Resources, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration, Supervision.

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.

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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.2021.108433.

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