Food Control 165 (2024) 110655

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

Effectiveness of official food safety control in Barcelona city: Digital and traditional inspections

Eduard Grau-Noguer [a,b,*], Maica Rodríguez-Sanz [b,c,d], Remo Suppi [e], Jordi Serratosa [f], Janne Lundén [g], Assun Bolao [b,d], Desireé Cedano [b], Samuel Portaña [a,b,d]

[a] Departament de Ciència Animal i dels Aliments, Facultat de Veterinària, Universitat Autònoma de Barcelona, Cerdanyola del Vallès (Barcelona), Spain
[b] Agència de Salut Pública de Barcelona (Public Health Agency, Barcelona), Barcelona, Spain
[c] CIBER Epidemiología y Salud Pública (CIBERESP), Madrid, Spain
[d] Institut d'Investigació Biomèdica (IIB Sant Pau), Barcelona, Spain
[e] Departament d'Arquitectura de Computadors i Sistemes Operatius, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Barcelona, Spain
[f] German Federal Institute for Risk Assessment (BfR), Berlin, Germany
[g] Department of Food Hygiene and Environmental Health, Faculty of Veterinary Medicine, University of Helsinki, Helsinki, Finland

ARTICLE INFO

Keywords:
Food safety
Food control
Official food safety control
Effectiveness
Digitalization
Barcelona

ABSTRACT

Analysing the effects of using a digital environment in official food safety control and understanding its benefits is crucial for competent authorities. The aim of this paper was to assess the effectiveness of official control carried out by the Barcelona Public Health Agency between 2015 and 2022 in Barcelona city (Spain) at retail outlets following the transition from a traditional to a digital inspection. Effectiveness is defined as the ability to detect non-compliance during inspections. This study assessed 2,188 inspection reports of risk-based planned inspections from 2015 to 2019 (traditional inspection) and 2022 (digital inspection) to compare the detection of non-compliances. The results show a significant increase in the detection of non-compliance when using the digital inspection. Compared to all inspection areas studied, the highest prevalence difference in the detection of non-compliance using a digital environment was found for the areas of food processing and handling procedures (34.0%) and own controls (16.7%). On the other hand, the areas of food labelling and general cleanliness of premises and equipment showed the lowest difference, 11.1% and 7.9%, respectively. The present case study shows that the use of a digital environment during inspections positively supports the control officers in structuring the compliance judgement and being more sensible to detect non-compliance. This fact results in a greater effectiveness of food control.

1. Introduction

Food business operators (FBOs) are legally responsible for ensuring the successful implementation of food law in their businesses (EC 178/2002). Meanwhile, designated competent authorities (CAs) are responsible for carrying out risk-based official food safety control (hereafter, 'official control') in accordance with their territorial and material competences (EU 2017/625). Official control plays an essential public health role in protecting the health of consumers by preventing the spread of foodborne diseases throughout the food chain. This is achieved by verifying that FBOs comply with the law and by detecting the risk factors for foodborne diseases. In cases of non-compliance, the CAs have the power to take administrative enforcement measures to ensure that FBOs comply with the law and therefore correct the detected risk factors. The main applicable European Union (EU) food safety legislation is Regulation 178/2002 (EC 178/2002), Regulation 852/2004 (EC 852/2004) and Regulation 853/2004 (EC 853/2004).

The Codex Alimentarius *Principles and guidelines for national food control systems* (FAO/WHO, 2013) and Regulation 2017/625 (EU 2017/625) in the EU indicate that official control must be effective. The effectiveness of official control can be defined as the extent to which the objectives of food control systems are achieved (FAO/WHO, 2017) or equivalently, the extent to which official control achieves an objective (National Audit Systems Network, 2014). Berking et al. (2019)

* Corresponding author. Departament de Ciència Animal i dels Aliments, Facultat de Veterinària, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, Barcelona, Spain.
E-mail addresses: eduard.grau@uab.cat, egrau@aspb.cat (E. Grau-Noguer).

https://doi.org/10.1016/j.foodcont.2024.110655
Received 26 March 2024; Received in revised form 10 June 2024; Accepted 13 June 2024
Available online 13 June 2024

alternatively interpret effectiveness as the capacity of official control to detect non-compliances during inspections. Läikkö-Roto et al. (2015) stated that the effectiveness of official control depends on the ability to ensure that FBOs correct non-compliances. Although effectiveness is a pillar of official control, it is often criticised for being ineffective (Barnes et al., 2022; Griffith, 2005; Yapp & Fairman, 2006). Failure to implement effective control may have public health implications, reduce the prevention of foodborne diseases, and ultimately lead to low consumer health protection (National Audit Systems Network, 2014).

The Barcelona Public Health Agency is the CA in the city of Barcelona (Spain) responsible for implementing official control of foodstuffs and food hygiene at the retail and industrial levels. Historically, the Barcelona Public Health Agency documented and transmitted the findings of official food safety inspections of retail outlets using a paper-based system (hereafter 'traditional inspection') (Supplementary material A1). Each inspection was documented in a handwritten report, which broadly described only the non-compliances detected in an unstructured qualitative manner. There was no mechanism in place to ensure that all possible non-compliances were fully assessed during an inspection. Subsequently, a hard copy of the report was provided to the FBOs. Upon returning to the office, the control officers transcribed the non-compliances detected in the Barcelona Public Health Agency's digital registry database. The traditional inspection was more oriented towards a food safety risk assessment, as proposed by Barnes et al. (2024). In this instance, the risk assessment was based on the risk perceived by officers in accordance with the specific circumstances, their experience and internal criteria.

As of 2021, the Barcelona Public Health Agency has moved from a paper-to a digital-based system (hereafter 'digital inspection') using a digital environment to support control officers during on-site inspections of retail outlets (FAO, 2024a). This change aimed to improve the consistency and the effectiveness on how non-compliances are assessed, recorded and documented. The term 'digital environment' refers to the use of digital devices and programs to record, analyse, and transmit data and information between CAs, FBOs or other stakeholders (Grau-Noguer et al., 2023). The digital inspection includes a standardised compliance checklist supported by a mobile digital cloud-based platform (Barcelona Public Health Agency, 2023; FAO, 2024a) (Supplementary material A2). In contrast to the traditional inspection, the digital inspection provides a systematic reminder to officers of all non-compliances that may be detectable during any inspection via a drop-down menu list. In addition, the digital inspection also provides a brief explanation of each non-compliance. Furthermore, the new inspection procedure requests officers to indicate whether non-compliances have been detected using a binary system: 'detected' or 'not detected'. This implies that officers assess the FBOs' compliance in its entirety, which results in the reporting of both those non-compliances that have been detected and those that have not. The digital inspection is oriented toward a compliance check inspection approach (Barnes et al., 2024). Based on the number of non-compliances and their severity, a compliance score is calculated for the entire inspection using predefined rule-based instructions. According to this score, the digital environment automatically sets the result of the inspection, the deadlines for the FBOs to correct the non-compliances detected and, if necessary, determines the enforcement measures. After each inspection, the resulting report is automatically generated based on a template, emailed to the FBOs in PDF format, and uploaded and stored on the cloud server of the Barcelona Public Health Agency. Control officers can access its contents at any time, either from the office or during inspections.

By systematising and standardising processes during inspections, inconsistencies among control officers are minimised (Gawande, 2010; Griffith, 2005; Kahneman et al., 2021; Läikkö-Roto et al., 2015) and, in the case of Barcelona, the consistency of the overall inspection notably increased (FAO, 2024a). The traditional inspection lacked adequate measures to ensure and verify the effectiveness of official control. This was due to the qualitative nature of the analysis of inspection data, which made it difficult and time consuming. In addition, it was difficult to draw valid and consistent conclusions and to compare results.

In the EU, a multi-country survey found that CAs, whether local, regional or national, are using digital technologies to standardise data collection during inspections and reporting to national or EU authorities, or to improve the consistency of official control (Grau-Noguer et al., 2023). However, to our knowledge, the only study aiming to assess how the use of digital technologies during inspections affects the effectiveness of official control was conducted by Zhe Jin and Lee (2014) in the State of Florida (United States). They concluded a positive increase of the effectiveness after using such technologies compared to the previous paper-based inspection.

In response to the lack of scientific literature and case studies on the impact of the use of digital technologies on official control and its impact on performance, the Barcelona Public Health Agency initiated a research project entitled 'Digital transformation of the official food safety control in Barcelona'. Within the framework of this project, and considering that the use of digital technologies to support official control activities will increase in the coming years, and that policy and decision makers from CAs will need strong arguments to support the implementation and continued use of such technologies, this study aimed to 1) investigate the extent to which the detection of non-compliance during inspections differs between the digital and traditional inspections in the city of Barcelona between 2015 and 2022, and 2) assess which areas of inspection differ more between the two inspections. Our hypothesis was that the use of digital technologies to assist control officers during inspections would increase the detection of non-compliance.

2. Materials and methods

2.1. Study design, population and source of information

We conducted a cross-sectional study of the inspections in the city of Barcelona, following the transition from a traditional to a digital inspection, the period 2015–2019 (traditional) and the year 2022 (digital). Due to the specific context of the COVID-19 pandemic and measures such as temporary closures of food retail outlets, the year 2020 was excluded. Further to this, no risk-based planned inspections of retail outlets were carried out this year, only inspections in response to food safety alerts or foodborne outbreaks. In addition, 2021 was also excluded because the digital environment was being implemented, and therefore, the use of digital technologies in inspections was not yet mature and fully functional until 2022. The transition to the digital inspection was slow and highly changing, as the digital environment was piloted and adjusted several times before the final version was adopted.

The population for our study were food retail outlets located in Barcelona. By retail outlet we mean any food establishment where food is handled, transformed and stored at the point of sale or delivery to the final consumer (EC 178/2002). Our research included butcher, fish, bakery, fruit and vegetable, ice cream and small grocery retail outlets. Restaurants, institutional catering, or any other retail outlets, such as supermarkets, were not included because the use of digital technologies to support planned inspections for these establishments was being implemented at the time of the study.

Our source of information was the Barcelona Public Health Agency's digital registry database. This registry contains data from the inspection reports of all inspections carried out.

The study included 2,188 inspection reports of all risk-based planned inspections conducted during the period covered by the study. From 2015 to 2019, a total of 1,650 inspections were carried out through the traditional inspection, and in 2022, 538 inspections were carried out through the digital (Table 1). The risk-based planning and organisation of inspections are the same in the digital and traditional inspections. Planned inspections are programmed annually based on the risk classification of the outlets and the available resources, both human and economic. In addition, planned inspections are also subject to unplanned

Table 1
Inspection reports analysed (N = 2,188) across digital (n = 538) and traditional (n = 1,650) inspections, stratified by type of retail outlet.

Type of retail outlet	Inspection reports		Total
	Digital	Traditional	
Bakery	239	449	688
Fruit and vegetable	107	121	228
Small grocery	78	327	405
Fish	51	209	260
Butcher	45	496	541
Ice cream	18	48	66
Total	538	1,650	2,188

control activities that require an immediate and urgent response, such as food safety alerts, outbreak investigations or police interventions. For outlets that were inspected on more than one occasion during the study period as part of planned inspections, only data from the first planned inspection was considered in order to prevent any potential influence of differences in inspection frequency on the prevalence of non-compliance.

The top three retail outlets with the highest number of inspections were bakery, butcher and small groceries outlets (Table 1). In comparison, ice cream and fruit and vegetable outlets were the least frequently inspected outlets.

2.2. Variables

The **dependent variables** for this study were those related to the inspection process that could be affected by the implementation of the digital inspection:

- The total number of inspection areas where non-compliance was detected. In our study, non-compliances were grouped into the following six inspection areas: 1) design and maintenance of premises and equipment, 2) general cleanliness of premises and equipment, 3) food processing and handling procedures, 4) food labelling, 5) food traceability, and 6) own controls. Non-compliances were grouped in these areas according to the way they were documented and registered in the traditional inspection. In the traditional inspection, the control officers recorded the areas where non-compliances were found in the digital registry database of the Barcelona Public Health Agency, according to the six areas of inspection that we used in this study to group non-compliances. However, they did not provide further details on the number of non-compliances detected per area, a description of the nature of the non-compliances or their severity.
- Detection of non-compliance by each of the above six inspection areas with binary categories of either detection or non-detection.

The **independent variable** was the type of inspection used to support officers, either digital or traditional.

2.3. Data analysis

We first compared the number of inspection areas where non-compliance was detected between the digital and traditional inspections by describing the distribution using means and stratifying by type of retail outlet. Given the normal distribution of the data, we used Student's t-tests to compare the means.

Secondly, we compared the detection of non-compliance between the digital and traditional inspections by using proportions and stratifying by type of retail outlet. We tested for differences between the two inspections using Pearson's chi-squared tests. In addition, to describe the magnitude of the change in the detection of non-compliance between the two inspections, we described this change using prevalence difference (digital inspection - traditional inspection), expressed as percentage points. Corresponding 95% confidence intervals (CI) were calculated for both metrics. A positive prevalence difference indicated an increase in the detection of non-compliance by digital inspection, whereas a negative prevalence difference indicated a decrease in detection. We chose prevalence rate ratios as our measures of this association because they are more consistent, easier to interpret, and do not overestimate the strength of the association compared to other association metrics such as odds ratio or prevalence odds ratio (Barros & Hirakata, 2003; Espelt et al., 2019; Schiaffino et al., 2003). Additionally, given the nature of our study, it is recommended to employ prevalence rate ratios over prevalence odds ratios when conducting cross-sectional studies with binary outcomes (Grimes & Schulz, 2008; Martinez et al., 2017; Thompson et al., 1998; Zocchetti et al., 1997).

Inspection data were downloaded as Microsoft Excel spreadsheets from the digital registry database of the Barcelona Public Health Agency, and rigorous data cleaning and consistency checks were carried out. Statistical analyses were performed using Stata 15.1 software (StataCorp LLC. College Station, TX, USA). All figures were created using RStudio version 2024.04.0 + 735 (RStudio Team, 2020). A p-value of <0.05 was considered statistically significant for all statistical tests.

3. Results

3.1. Total number of inspection areas with non-compliance

When comparing the mean number of inspection areas with non-compliance between the digital and traditional inspections, statistically significant differences were found, with a higher detection of non-compliance using the digital inspection (Table 2). Overall, the mean number of inspection areas with non-compliance was 3.85 for the digital and 3.06 for the traditional inspections (p-value<0.001). Similarly, between the different types of retail outlet, there was a significant increase in the number of areas of inspection with non-compliance with the digital inspection in all outlets except fish outlets. Although observing an increase in the detection of non-compliance in the latter case, no significant difference was found. The greatest differences in the mean values were observed for ice cream and bakery outlets.

3.2. Detection of non-compliance by inspection area

Based on our results, the digital and traditional inspections detected a higher proportion of non-compliance in the inspection areas of design and maintenance of premises and equipment (94.6% and 83.3%, respectively) and own controls (93.5% and 76.8%, respectively) (Table 3 and Supplementary material B). Conversely, the lowest detection of non-compliance by both inspections was found in the areas of food traceability (22.7% and 8.7%, respectively) and food labelling had (40.1% and 29.0%, respectively).

Table 2
Differences in the mean number of inspection areas with non-compliance detected between the digital (n = 538) and traditional (n = 1,650) inspections, stratified by type of retail outlet.

Type of retail outlet	Mean number of inspection areas with non-compliance		*p*-value[a]
	Digital (n)	Traditional (n)	
Bakery	4.10 (239)	3.00 (449)	<0.001
Fruit and vegetable	3.66 (107)	3.07 (121)	<0.001
Small grocery	3.68 (78)	2.92 (327)	<0.001
Fish	3.45 (51)	3.20 (209)	0.276
Butcher	3.69 (45)	3.19 (496)	0.020
Ice cream	4.00 (18)	2.56 (48)	<0.001
Overall	3.85 (538)	3.06 (1,650)	<0.001

[a] The p-values were calculated with the T-Student test.

Table 3
Proportion and prevalence difference of the detection of non-compliance between the digital (n = 538) and traditional (n = 1,650) inspections.

Area of inspection	Proportion of detection of non-compliance (n)		*p*-value[a]	Prevalence difference (95% CI[b])
	Digital (n = 538)	Traditional (n = 1,650)		
Food processing and handling procedures	77.7 (418)	43.7 (721)	<0.001	34.0 (29.7, 38.3)
Own controls	93.5 (503)	76.8 (1,267)	<0.001	16.7 (13.8, 19.6)
Food traceability	22.7 (122)	8.7 (143)	<0.001	14.0 (10.2, 17.8)
Design and maintenance of premises and equipment	94.6 (509)	83.3 (1,374)	<0.001	11.3 (8.7, 14.0)
Food labelling	40.1 (216)	29.0 (479)	<0.001	11.1 (6.4, 15.8)
General cleanliness of premises and equipment	55.4 (298)	47.5 (784)	0.002	7.9 (3.0, 12.7)

[a] The p-values were calculated with the Pearson's chi-squared test.
[b] CI, confidence interval.

When assessing which inspection areas differed more between the two inspections, a higher detection of non-compliance was observed in all inspection areas using the digital inspection and with statistically significant differences. The areas of inspection of food processing and handling procedures (34.0%) and own controls (16.7%) had the highest prevalence difference (Table 3). Contrary, the two areas of inspection with lowest prevalence difference were food labelling (11.1%) and general cleanliness of premises and equipment (7.9%).

In line with the above, when comparing the inspection areas in which more non-compliance was detected, stratified by type of retail outlet, the areas of own controls and design and maintenance of premises and equipment were the most recurrent areas in both inspections and in all retail outlets (Table 4, Supplementary material C). Following the same trend, for all outlets the two inspection areas with less detected non-compliance were food traceability and food labelling, apart from butcher and fish outlets, where general cleanliness of premises and equipment was one of the two inspection areas with less detected non-compliance.

The results of the assessment of the magnitude change in non-compliance detection between the two inspections varied depending on the type of retail outlet and inspection area (Table 4). Despite of this, using the digital inspection, compared to the traditional one, the prevalence difference increased in all outlets and inspection areas, except for the general cleanliness of premises and equipment in bakery (−5.0%) and butcher (−7.4%) outlets, and more substantially, in food labelling in fish (−27.2%) and fruit and vegetable (−21.6%) outlets.

Consistent with the overall detection prevalence (Table 3), the inspection area of food processing and handling procedures showed the highest prevalence difference in small grocery (40.5%), ice cream (39.6%) outlets, and the second highest in bakery (42.9%), fruit and vegetable (23.0%) and butcher (17.3%) outlets (Table 4). The area of own controls had the highest prevalence difference in fish outlets (25.7%) and the second highest in small grocery (17.9%) outlets.

In addition to the above-mentioned areas with the lowest prevalence difference, in ice cream outlets, the inspection area of own controls had the lowest prevalence difference (7.6%). Design and maintenance of premises and equipment had the second lowest prevalence difference in ice cream (10.4%), fruit and vegetable (9.7%), and bakery (9.4%) (Table 4).

Table 4
Proportion and prevalence difference of the detection of non-compliance between the digital and traditional inspections, stratified by type of retail outlet.

Type of retail outlet (n digital inspections/ n traditional inspections)	Area of inspection	Proportion of detection of non-compliance (n)		*p*-value[a]	Prevalence difference (95% CI[b])
		Digital	Traditional		
Bakery (239/449)	Food processing and handling procedures	84.1 (201)	41.2 (185)	<0.001	42.9 (36.4, 49.4)
	Own controls	93.3 (223)	79.7 (358)	<0.001	13.6 (8.7, 18.5)
	Food traceability	22.2 (53)	5.8 (26)	<0.001	16.4 (10.7, 22.1)
	Design and maintenance of premises and equipment	95.8 (229)	86.4 (388)	<0.001	9.4 (5.3, 13.5)
	Food labelling	59.8 (143)	10.5 (47)	<0.001	49.4 (42.5, 56.2)
	General cleanliness of premises and equipment	53.6 (128)	58.6 (263)	0.206	−5.0 (−12.8, 2.8)
Fruit and vegetable (107/121)	Food processing and handling procedures	77.6 (83)	54.5 (66)	<0.001	23.0 (11.1, 34.9)
	Own controls	96.3 (103)	76.9 (93)	<0.001	19.4 (11.1, 27.7)
	Food traceability	20.6 (22)	4.1 (5)	<0.001	16.4 (8.0, 24.9)
	Design and maintenance of premises and equipment	90.7 (97)	81.0 (98)	0.039	9.7 (0.8, 18.6)
	Food labelling	13.1 (14)	34.7 (42)	<0.001	−21.6 (−32.2, −11.0)
	General cleanliness of premises and equipment	68.2 (73)	43.0 (52)	<0.001	25.2 (12.8, 37.7)
Small grocery (78/327)	Food processing and handling procedures	76.9 (60)	36.4 (119)	<0.001	40.5 (29.8, 51.2)
	Own controls	89.7 (70)	71.9 (235)	0.001	17.9 (9.6, 26.2)
	Food traceability	15.4 (12)	7.3 (24)	0.025	8.0 (−0.4, 16.5)
	Design and maintenance of premises and equipment	97.4 (76)	86.5 (283)	0.006	10.9 (5.8, 16.0)
	Food labelling	19.2 (15)	15.0 (49)	0.356	4.2 (−5.3, 13.8)
	General cleanliness of premises and equipment	65.4 (51)	56.3 (184)	0.143	9.1 (−2.7, 21.0)
Fish (51/209)	Food processing and handling procedures	56.9 (29)	40.7 (85)	0.037	16.2 (1.1, 31.3)
	Own controls	96.1 (49)	70.3 (147)	<0.001	25.7 (17.6, 33.9)
	Food traceability	37.3 (19)	26.8 (56)	0.139	10.5 (−4.1, 25.0)
	Design and maintenance	94.1 (48)	72.7 (152)	0.001	21.4 (12.5, 30.2)

(*continued on next page*)

Table 4 (*continued*)

Type of retail outlet (n digital inspections/ n traditional inspections)	Area of inspection	Proportion of detection of non-compliance (n)		*p*-value[a]	Prevalence difference (95% CI[b])
		Digital	Traditional		
	of premises and equipment				
	Food labelling	21.6 (11)	48.8 (102)	<0.001	−27.2 (−40.4, −14.1)
	General cleanliness of premises and equipment	39.2 (20)	37.3 (78)	0.802	1.9 (−13.0, 16.8)
Butcher (45/ 496)	Food processing and handling procedures	66.7 (30)	49.4 (245)	0.027	17.3 (2.8, 31.7)
	Own controls	93.3 (42)	79.6 (395)	0.026	13.7 (5.6, 21.8)
	Food traceability	24.4 (11)	6.3 (31)	<0.001	18.2 (5.5, 30.9)
	Design and maintenance of premises and equipment	91.1 (41)	82.7 (410)	0.145	8.4 (−0.5, 17.4)
	Food labelling	60.0 (27)	47.8 (237)	0.116	12.2 (−2.8, 27.2)
	General cleanliness of premises and equipment	31.1 (14)	38.5 (191)	0.327	−7.4 (−21.6, 6.8)
Ice cream (18/48)	Food processing and handling procedures	83.3 (15)	43.8 (21)	0.004	39.6 (17.4, 61.8)
	Own controls	88.9 (16)	81.3 (39)	0.458	7.6 (−10.6, 25.9)
	Food traceability	27.8 (5)	2.1 (1)	0.001	25.7 (4.6, 46.8)
	Design and maintenance of premises and equipment	100.0 (18)	89.6 (43)	0.154	10.4 (1.8, 19.1)
	Food labelling	33.3 (6)	4.2 (2)	0.001	29.2 (6.7, 51.7)
	General cleanliness of premises and equipment	66.7 (12)	33.3 (16)	0.015	33.3 (7.8, 58.9)

[a] The p-values were calculated with the Pearson's chi-squared test.
[b] CI, confidence interval.

4. Discussion

This innovative study assesses the effectiveness of official control following the implementation of a digital environment to assist control officers in inspecting retail outlets in Barcelona city. Our study shows that the transition from a traditional to a digital inspection resulted in an increase in the detection of non-compliance. This led to an improvement in the effectiveness of official control. Our findings are consistent with the only case study described in the scientific literature that addresses the same issue (Zhe Jin & Lee, 2014). Compared to the available scientific evidence, our research extends the assessment to also other types of retail outlet and inspection areas. In contrast to all the inspection areas studied, the area of food processing and handling procedures showed the highest increase in the detection of non-compliance using a digital environment.

The benefits of using digital technologies to support official control are being evaluated (Grau-Noguer et al., 2023; Hunka et al., 2024; Kautto et al., 2023; Melkamu et al., 2024; OECD, 2023) and discussed at the international level (FAO/WHO, 2023). Although their use for remote meat inspection is not permitted in the EU under Regulation 2017/625 (EU 2017/625), there are no legal restrictions on their use to assist control officers during on-site inspections. Advocating for the digital transformation of official control should be a priority for CAs, considering how the opportunities offered by digital technologies can successfully address the limitations of traditional inspections to effectively achieve the goals of fairness, quality, consistency and effectiveness. Our research is timely as CAs are increasingly using digital technologies to carry out official control tasks (FAO, 2024b; Grau-Noguer et al., 2023). Nevertheless, given the scenario of a lack of scientific evidence and case studies on this issue, the findings of this study may influence and help policy makers in CAs to consider the implementation of digital technologies to support inspections and improve the delivery of official control. Furthermore, given the increasing number of outbreaks, human cases, hospitalisations and deaths associated with foodborne diseases in the EU (EFSA & ECDC, 2023), it is important to consider new methods to improve the effectiveness of official control and reduce the transmission and burden of foodborne diseases.

In the EU, CAs using a digital environment during inspections indicated that the main reason for using such an environment was to standardise the data recording process (Grau-Noguer et al., 2023). According to Kahneman et al. (2021), professional complex human judgement, as control officers do when assessing non-compliance during inspections, is contingent on the so-called 'noise'. Noise is the unpredictable and unwanted variability influencing consistency in decision-making. Even judgement from very skilled and trained professionals suffers from unconsciously generated noise. Structuring a complex judgement into smaller judgements helps to minimise inconsistent assessment, in our case, between control officers, as well as being more sensible to detect non-compliances. Structuring is understood as the decomposition of the whole judgement into smaller parts with the objective of guiding the assessment and ensuring that each part is assessed independently of the others, and that the focus is on the smaller parts rather than the whole judgement (Kahneman et al., 2021). It is wise to highlight that non-compliance assessment is mostly based on qualitative judgement rather than quantitative, and the former is more likely to suffer from noise. In relation to this structuring, the Barcelona Public Health Agency has transitioned from an open procedure of assessing and documenting non-compliance to a standard procedure supported by a digital environment (Supplementary material A). This new procedure acts as a 'roadmap' for officers during inspections, guiding them through rule-based instructions and reminding them of any non-compliance that may be detected. This change has led to an increase in the detection of non-compliance. In addition, the current digital inspection asks control officers to indicate whether a non-compliance has been detected or not. This requires them to assess all possible and detectable non-compliances during all risk-based planned inspections.

When comparing the number of areas of inspection with non-compliance between the digital and traditional inspection, we observed the same trend in all retail outlets. This confirms that a structured inspection is more effective in detecting non-compliances. Following the same rationale, detection of non-compliance increased in all areas of inspection likewise. However, not all areas of inspection increased similarly. Compared to all areas of inspection, the area of food processing and handling procedures increased the most. We argue that the assessment of this inspection area is more complex than that of other areas (design and maintenance and general cleanliness of premises and equipment, food labelling, food traceability and own controls). In our opinion, the assessment of the former is more complex due to the knowledge required from the officers' side at the moment of inspection of the law and food processing processes, as well as the number and variety of non-compliances that may be detectable. Compared to the

traditional inspection, we attribute this increase to the structured compliance judgement provided by the digital inspection, which involves listing all non-compliances that may be detectable, providing a brief description of their nature and forcing officers to indicate whether non-compliances have been detected or not through rule-based instructions. In that sense, officers are reminded of all non-compliances that may be detected and thus it enables a more in-depth, detailed and systematic compliance judgement and greater opportunities to detect more non-compliances. We argue that the assessment of non-compliance of food labelling, food traceability, own controls and design, maintenance and general cleanliness of premises and equipment is more of a 'black and white' answer compared to food processing and handling procedures, which require a more structured judgement to facilitate control officers the detection of non-compliance.

The use of digital technology in support of professional workers enhances the quality of work and the ability to make more accurate decisions (Raisch & Krakowski, 2021). Just as digital technologies are being used in healthcare to support and improve medical diagnosis (Göndöcs & Dörfler, 2024; Hazarika, 2020), digital technologies can be used in official control to support control officers in better 'diagnosing' FBO compliance. In this sense, the use of a digital environment to support compliance assessments improves the quality and detail of the assessment and increases the ability to detect non-compliance, and therefore, the effectiveness of food control. Additionally, as pointed out by Falzon et al. (2021), paper-based data recording at the abattoir level, compared against digital recording, is perceived as inadequate, lacking detail, and error-prone.

The impact of consuming unsafe food on public health is well documented (EFSA & ECDC, 2023). However, the effect of official control on public health is scarce. Although there is limited scientific evidence, studies have shown that higher non-compliances observed during planned inspections in retail outlets is associated with outbreaks or incidences of infectious foodborne diseases (Firestone et al., 2020; Irwin et al., 1989; Kosola et al., 2023). Firestone et al. (2020) suggest that the use of aggregate inspection data could aid in foodborne illness surveillance and prevention strategies. Machine learning technology, for example, can be applied to inspection data to forecast future food safety adverse events (Deng et al., 2021; Wang et al., 2022) or providing early warning of such events (Geng et al., 2017). Machine learning could be also used to process data from websites, blogs, or social media, which could then be used by CAs to manage food safety issues (Mu et al., 2024). Grimaldi et al. (2021) found a positive correlation between inspection scores of restaurants and online-generated reviews from TripAdvisor in New York City (United States). Those findings suggest that data triangulation could be a practical consideration for decision-making and prioritising official control tasks. Data mining and analysis for decision making would require the incorporation of new staff profiles related to data processing in CAs. In this sense, a case study by van der Voort et al. (2021) describes the use of data analysts by the Netherlands Food and Consumer Product Safety Authority to assist control officers in predicting high-risk businesses. The authors of this study highlighted the importance of creating a mutual understanding of perspectives between control officers and data analysts.

According to Falzon et al. (2021), the use of digital technology to record non-compliance can improve the detail of inspection documentation compared to paper-based data recording. While this study does not address it, an increase in the effectiveness of official control in relation to a higher detection of non-compliance could also improve its influence on FBOs to correct the detected non-compliances. FBOs are more knowledgeable about the compliance status of their retail outlets and have a greater opportunity to rectify any non-compliances identified during inspections. Recording non-compliances in a digital format during inspections could facilitate the creation of a platform for communication between FBOs and CAs. This platform would enable the exchange and sharing of inspection-related information, as well as cooperation between them (Mu et al., 2024).

This study shows that the use of a digital environment during inspections not only improves the effectiveness of official control but also serves as a prerequisite for collecting data in a standardised digital format for processing. Standardisation of the data collection process between control officers is essential to ensure quality official control data. Data quality encompasses various characteristics, including accuracy, timeliness, completeness, consistency or relevance (Miller, 1996; Strong et al., 1997). In this respect, data-driven decision making in law enforcement should rely on data collected through standardised procedures (Mu et al., 2024; Thakkar et al., 2023). This context could facilitate the implementation of a valid and consistent disclosure system for inspection results, as suggested by Kim et al. (2022).

Our study found a notable rise in the detection of non-compliance in the inspection area of food processing and handling procedures after the implementation of the digital inspection in all the outlets included in the study. We attribute this increase to the heightened sensitivity of detecting non-compliance by structuring the judgement. Food contamination leading to outbreaks can occur before, during and after processing (Kase et al., 2017). However, during the processing, events such as cross-contamination, undercooking, insufficient physical protection, or long-term exposure to improper holding temperatures may occur and put the safety of the prepared food at risk (AL-Mamun et al., 2018). For example, *Escherichia coli* and *Campylobacter* outbreaks have been respectively linked to the consumption of undercooked or contaminated beef (Yahata et al., 2015), and poultry meat (Batz et al., 2012). On the other hand, high detection of non-compliances related to food processing has been linked to an increased incidence of campylobacteriosis in specific geographical areas in Finland (Kosola et al., 2023). By reviewing food safety incidents and recalls between 2008 and 2018, Soon et al. (2020) found that the second cause of adverse incidents was cross-contamination. Furthermore, a quantitative risk assessment study conducted in the United States found that up to 84% of deaths from listeriosis associated with the consumption of turkey ham products were caused by cross-contamination with *Listeria monocytogenes* at the retail level (Pradhan et al., 2010), suggesting inadequate food handling practices by food business operators. In this relation, bad food-handling practices directly influence the safety of the processed food by increasing the likelihood of cross-contamination (Chen et al., 2024). Improving the effectiveness of detecting non-compliances related to food processing would enhance greater consumer health protection and could directly reduce adverse food safety events.

The digital inspection led to an increase in the detection of non-compliance in own controls in all the retail outlets studied. In Spain, compliance on the correct implementation of own controls decreased from 84.2% to 49.3% between 2017 and 2021 (Spanish Agency for Food Safety and Nutrition, 2022). Contrary to the national trend, after implementing a digital inspection, the detection of non-compliances related to own controls has increased in Barcelona. The detail of the compliance assessment during the inspection provided by the structured digital environment helps to increase the detection of non-compliance.

It is well proven that having food safety procedures based on Hazards and Critical Control Points (HACCP) principles in place is an effective instrument to reduce the transmission of diseases through food (Fortin et al., 2021; Milos et al., 2017). FBOs' implementation of a HACCP self-control system may be contingent on a lack of knowledge, motivation and training (Radu et al., 2023). From industrial and retail levels, all food processing relies on permanent procedures based on HACCP principles. The successful implementation of a HACCP self-control system by retail FBOs may be challenging and depend on staff knowledge, expertise and turnover, cost, motivation or record keeping (EFSA BIOHAZ Panel, 2017; Radu et al., 2023). The aim of those procedures is to mitigate all potential health risks for consumers by identifying, preventing, eliminating, reducing any food hazards at any stage of food production, processing and distribution of food (EC 852/2004). To demonstrate compliance with the law, FBOs must provide evidence of their implementation and maintenance through documentation of the

procedures and records. Given that retail outlets are usually owned by a single person, have little help in dealing with management issues or only serve local customers (Taylor, 2001), compared to the industrial sector, flexibility in the implementation of own controls is needed (EC 852/2004). Therefore, retail establishments need to comply with a food safety system based on the provision of prerequisite programmes (EC 2016/C 278/01), deemed sufficient to ensure food safety (EFSA BIOHAZ Panel, 2017).

The effectiveness of detecting non-compliance related to the inspection area of food traceability has improved after implementing a digital environment for its assessment, compared to the traditional inspection. FBOs are responsible for identifying and documenting information about food, or any substance intended for use in food, throughout the food chain (EC 852/2004). On the other hand, CAs are responsible for ensuring that FBOs have traceability systems in place to guarantee one step forward and one step back along the chain and to react to any potential risks as effectively as possible (EC 178/2002). Higher traceability standards improve trust and confidence among all actors involved in the food chain (Christopher & Lee, 2004; Razak et al., 2023). Increased sensitivity in detecting non-compliance in this inspection area ensures an effective history of food traceability and information about its movement along the supply chain. In instances of foodborne disease outbreaks associated with untraceable products, there is limited capacity to timely respond to public health threats, conduct outbreak investigations, or promptly recall and withdraw suspicious food from the market.

The effectiveness of detecting non-compliance related to the inspection area of design and maintenance of premises and equipment was increased through the use of a digital environment. Following the above-mentioned rationale for the previous two areas, the increased detection of non-compliance with the design and maintenance of premises and equipment is similar to the traditional inspection because the assessment of this inspection area relies on visual assessment. Nevertheless, having a more structured inspection tool helps in detecting more non-compliant situations. The design and maintenance of premises and equipment play a crucial role in food establishment premises. Either dimensions, materials, installation and accessibility or lack of maintenance are important aspects of preserving the safety of the food processed (Ahuja, 2017). Unwell-designed premises and the installation of equipment may limit access to specific areas, and therefore, this would represent a problem to ensure cleanliness, maintenance or pest control (Holah, 2024). Poor hygienic design of processing equipment and premises is thought to contribute to persistent microbiological colonisation and cross-contamination (EFSA BIOHAZ Panel, 2024). The so-called harbourage sites (niches), the unhygienic design of equipment and premises or damaged materials, are risk factors for the growth of, for example, pathogens like *Listeria monocytogenes* (Carpentier & Cerf, 2011; Gil et al., 2024) or *Pseudomonas* (Van Houdt & Michiels, 2010), linked also to the presence of other food-contaminant microorganisms such as *Salmonella enteritidis* (Zarei et al., 2023).

The use of the new structured inspection procedure guiding control officers on what must be assessed during inspections regarding information provided on food labels has increased compared to the traditional inspection, which leads to a higher effectiveness of official control and protection for consumers. We attribute the increase in the detection of non-compliance related to this inspection area to a greater detection particularly in those outlets where food is either packaged or repackaged and sold at the point of sale: butcher, bakery and ice cream outlets. For example, an assessment of ready-to-eat foods (deli meat products, cheese, pâté/foie and cured ham) sliced or cut into smaller portions and packaged at the point of sale to the final consumer in butcher outlets in Barcelona found that 49% of the samples did not carry a 'use by' date (Catalan Food Safety Agency, 2022). A possible explanation for the lower detection of non-compliances in fish and fruit and vegetable outlets is that in those outlets, food is sold in bulk and is not packaged. In the EU, Regulation 1169/2011 (EU 1169/2011) establishes the mandatory information required for food labelling. This information includes, among others, the name of the food, the list of ingredients, including those causing allergies or intolerances, the date of minimum durability, the 'use by' date, or any special storage conditions. For example, a lack or unclarity of information about ingredients may put consumers at risk (Fiocchi et al., 2021; Gallo et al., 2020). At the EU level, according to the Rapid Alert System for Feed and Food, in 2022, the most recurrent non-compliances (35.2%) were related to labelling (European Commission, 2023). In Spain, non-compliances of labelling of ingredients causing allergies or intolerances are the most commonly detected (Spanish Agency for Food Safety and Nutrition, 2022).

The implementation of the digital inspection has also resulted in an increase in the detection of non-compliance related to the general cleanliness of premises and equipment. Nevertheless, when considering outlet by outlet, a few exceptions were observed. Despite not augmenting the detection of non-compliance in two cases (bakeries and butchers), as it happens with the rest of the outlets, the effectiveness of the digital inspection is close to the traditional one. The similarity between the results of the traditional and digital inspections is attributed to the fact that cleanliness compliance is mainly assessed by visual observation. Inadequate cleanliness and sanitation of food processing environments can lead to microbiological contamination of food (De Oliveira Mota et al., 2021), evolving to a persistent presence at the same premises or equipment (EFSA BIOHAZ Panel, 2024). Environmental contamination of food processing facilities has been identified as the root cause of several foodborne outbreaks (Fernández-Martínez et al., 2022; Lyytikäinen et al., 2000; Simmons & Wiedmann, 2018; Thomas et al., 2020; Zacharski et al., 2018). In Finland, regions with a higher incidence of salmonellosis and campylobacteriosis were found to be linked to low compliance with the cleanliness of facilities, surfaces, and equipment (Kosola et al., 2023). The most common non-compliances associated with a *Salmonella* outbreak in restaurants were non-compliances in cleaning and sanitation of surfaces (Firestone et al., 2020). Given that *Salmonella* was identified in most foodborne outbreaks and that campylobacteriosis and salmonellosis were the two most commonly reported zoonotic diseases in humans in the EU in 2022 (EFSA & ECDC, 2023), detecting non-compliances related to cleanliness could lead to the prompt identification and prediction of potential risk situations associated with the presence of *Campylobacter* and *Salmonella*.

It is important to consider that visual assessments are limited to detecting persistent and long-term contamination of the food processing environments by pathogens able to create biofilms with public health implications (Bai et al., 2024). As observed by Kosola et al. (2023) in Finland, higher compliance was detected with cleanliness where the incidence of listeriosis was higher. An explanation for this could be that, since this microorganism is able to form biofilms (Colagiorgi et al., 2017) and still having pathogenic capacity, its presence can be hidden in seemingly clean stainless-steel tables when visually assessing cleanliness (Bai et al., 2024). A study conducted in the retail sector of Northern Spain found a higher prevalence of *Listeria monocytogenes* in in-store-packaged deli meat products (8.5%) compared to manufacturer vacuum-packaged presentations (2.7%) (Garrido et al., 2009). The authors of this study concluded that improved cleaning and disinfection procedures would mitigate the presence of this pathogen.

Our study has a number of limitations. Firstly, the data on the digital inspection covers one year after the new inspection was mature and fully implemented for the establishments included in this research. In our view, the results presented here are preliminary and further research is needed to assess the extent to which the detection of non-compliance will follow the same trend in the coming years. Secondly, the detection of non-compliance is examined by grouping them into six inspection areas and counting the number of areas where non-compliance was detected, but not the total number of non-compliances detected per area, the nature of the non-compliances nor their severity. Although those aspects are important, we were forced to count either the detection or non-detection of non-compliances per inspection area because of the

way in which non-compliances were registered in the former database of the Barcelona Public Health Agency, which was used with the traditional inspection. Thirdly, our study only focuses on a single city and specific retail outlets. This fact limits the generalisability of the results. Nevertheless, as stated above, we consider our results to be a preliminary investigation into the transition from traditional to digital inspections, which, given their novelty and contribution to the field of official control, deserve to be shared in order to stimulate research and enrich knowledge into the digital transformation of this field. Fourthly, compared to the traditional inspection, the digital one offers greater consistency between inspectors and authorities in assessing the compliance of FBOs. Nevertheless, we used officially reported inspection data, we suspect that the data from the traditional inspection may suffer from a degree of inconsistency due to the nature of the former inspection.

5. Conclusions and future work

Based on our study, we conclude that the use of digital technologies to assist control officers in carrying out on-site inspections has a positive effect on the detection of non-compliances during inspections in the city of Barcelona, contributing to an increase in the effectiveness of official control and thus to a higher level of consumer health protection. Although our research has limitations and it is not possible to draw general conclusions from the results, we believe that they do not question the importance and novelty to the field of official control in the context of scarce evidence on the subject and a global and inevitable digital transformation. Furthermore, in our view, the use of digital technology does not in itself guarantee greater effectiveness. The extent to which the detection of non-compliance increases depends on the design and structure of the digital environment itself.

Several local CAs in Catalonia (Spain) are currently adopting the digital inspection developed and employed by the Barcelona Public Health Agency. This uniformity in inspection procedures across different CAs could potentially reduce variability and allow for future research to compare their effectiveness. Using the same procedures will facilitate studying the consistency between CAs and conducting inter-calibration exercises and cross-inspections. Future research on the effects of using a digital environment in official control should focus not only on the number of non-compliances detected, their nature and severity, but also on their influence as risk factors for the detection (and prediction) of specific hazards in surveillance and outbreak investigation and their impact on the incidence of foodborne diseases. In addition, further research is also needed to address the limitations of our study and to assess the impact of the use of digital technologies on the effectiveness of official control in other geographical areas and sectors than retail, including industry and abattoir. According to Regulation 2017/625 (EU 2017/625), CAs in the EU should ensure and verify the effectiveness of official control. For this reason, continuous research should be enhanced to assess the extent to which the results of our study are consistent and how they evolve over the years in the city of Barcelona.

Cooperation, scientific research, and the exchange of good practices between CAs and academia in the field of official control are essential for discovering new mechanisms and methods to deal with the limitations of traditional inspection. This will increase the scientific foundation for implementing official control and aid in the efficient allocation of limited budgets and human resources by CAs, with the primary goal of achieving the greatest human health protection.

Funding

This study was supported by the Grant BEQU-2020-01 from the Barcelona Public Health Agency (Agència de Salut Pública de Barcelona, Spain).

CRediT authorship contribution statement

Eduard Grau-Noguer: Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Maica Rodríguez-Sanz:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Remo Suppi:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Jordi Serratosa:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Janne Lundén:** Writing – review & editing, Supervision, Methodology. **Assun Bolao:** Conceptualization. **Desireé Cedano:** Data curation. **Samuel Portaña:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

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.

Data availability

Data will be made available on request.

Acknowledgements

The authors of this paper are solely responsible for the opinions expressed and they do not necessarily represent the official views of their organisations. The authors would like to thank the Barcelona Public Health Agency (Agència de Salut Pública de Barcelona, https://www.aspb.cat) for providing data on the inspection reports. Furthermore, the authors would like to acknowledge all the control officers from the Barcelona Public Health Agency who carry out official control in Barcelona city. Without their work, this study could not have been conducted. The authors thank Tomás-Andrés Van Eeckhout Carter for the English grammar review.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodcont.2024.110655.

References

Ahuja, P. K. (2017). Design and construction of eating establishments for ensuring food safety. In *Food safety in the 21st century* (pp. 355–369). Elsevier. https://doi.org/10.1016/B978-0-12-801773-9.00028-5.

Al-Mamun, M., Chowdhury, T., Biswas, B., & Absar, N. (2018). Food poisoning and intoxication: A global leading concern for human health. In *Food safety and preservation* (pp. 307–352). Elsevier. https://doi.org/10.1016/B978-0-12-814956-0.00011-1.

Bai, X., Gallina, N. L. F., & Bhunia, A. K. (2024). Microbial biofilms in food safety and public health domains. In *Encyclopedia of food safety* (pp. 295–302). Elsevier. https://doi.org/10.1016/B978-0-12-822521-9.00250-1.

Barcelona Public Health Agency. (2023). *Planned inspection at retail establishments*. https://www.aspb.cat/es/documents/inspeccion-programada/.

Barnes, J., Smith, J., Ross, K., & Whiley, H. (2024). Performing food safety inspections. *Food Control, 160*, Article 110329. https://doi.org/10.1016/j.foodcont.2024.110329

Barnes, J., Whiley, H., Ross, K., & Smith, J. (2022). Defining food safety inspection. *International Journal of Environmental Research and Public Health, 19*(2). https://doi.org/10.3390/ijerph19020789

Barros, A. J., & Hirakata, V. N. (2003). Alternatives for logistic regression in cross-sectional studies: An empirical comparison of models that directly estimate the prevalence ratio cox regressioncross-sectional studieslogistic regressionodds ratioPoisson regressionprevalence ratiorobust variancestatistical models. *BMC Medical Research Methodology, 3*(21), 1–13. http://www.biomedcentral.com/1471-2288/3/21.

Batz, M. B., Hoffmann, S., & Morris, J. G. (2012). Ranking the disease burden of 14 pathogens in food sources in the United States using attribution data from outbreak investigations and expert elicitation. *Journal of Food Protection, 75*(7), 1278–1291. https://doi.org/10.4315/0362-028X.JFP-11-418

Berking, C., Vågsholm, I., Hedberg, L. M., Sörgjerd, S., & Niskanen, R. (2019). Non-compliances - an indicator of food control effectiveness. *Infection Ecology & Epidemiology, 9*(1). https://doi.org/10.1080/20008686.2019.1599276

Carpentier, B., & Cerf, O. (2011). Review — persistence of Listeria monocytogenes in food industry equipment and premises. *International Journal of Food Microbiology, 145*(1), 1–8. https://doi.org/10.1016/j.ijfoodmicro.2011.01.005

Catalan Food Safety Agency. (2022). Report on the establishment of the safe shelf life of certain ready-to-eat, sliced and pre-packaged foods in the retail trade in relation to the risk of Listeria monocytogenes. https://acsa.gencat.cat/web/.content/_Publicacions/Informes-tecnics/comite_cientific_assessor/publis/Listeria-en-llescats/ACSA_Informe_llescats-listeria_maquetat_CAT.pdf.

Chen, Y., Wan, G., Song, J., Dai, J., Shi, W., & Wang, L. (2024). Food safety practices of food handlers in China and their correlation with self-reported foodborne illness. *Journal of Food Protection, 87*(1), Article 100202. https://doi.org/10.1016/j.jfp.2023.100202

Christopher, M., & Lee, H. (2004). Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management, 34*(5), 388–396. https://doi.org/10.1108/09600030410545436

Colagiorgi, A., Bruini, I., Di Ciccio, P. A., Zanardi, E., Ghidini, S., & Ianieri, A. (2017). Listeria monocytogenes biofilms in the wonderland of food industry. *Pathogens, 6*(3), 41. https://doi.org/10.3390/pathogens6030041

Commission Notice on the Implementation of Food Safety Management Systems Covering Prerequisite Programs (PRPs) and Procedures Based on the HACCP Principles, Including the Facilitation/Flexibility of the Implementation in Certain Food Businesses (2016/C 278/01), Official Journal of the European Communities (C 278/1). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ%3AC%3A2016%3A278%3AFULL&from=EN.

De Oliveira Mota, J., Boué, G., Prévost, H., Maillet, A., Jaffres, E., Maignien, T., Arnich, N., Sanaa, M., & Federighi, M. (2021). Environmental monitoring program to support food microbiological safety and quality in food industries: A scoping review of the research and guidelines. *Food Control, 130*, Article 108283. https://doi.org/10.1016/j.foodcont.2021.108283

Deng, X., Cao, S., & Horn, A. L. (2021). Emerging applications of machine learning in food safety. *Annual Review of Food Science and Technology, 12*(1), 513–538. https://doi.org/10.1146/annurev-food-071720-024112

EFSA BIOHAZ Panel. (2017). Hazard analysis approaches for certain small retail establishments in view of the application of their food safety management systems. *EFSA Journal, 15*(3). https://doi.org/10.2903/j.efsa.2017.4697

EFSA BIOHAZ Panel. (2024). Persistence of microbiological hazards in food and feed production and processing environments. *EFSA Journal, 22*(1). https://doi.org/10.2903/j.efsa.2024.8521

EFSA, & ECDC. (2023). The European union one health 2022 zoonoses report. *EFSA Journal, 21*(12). https://doi.org/10.2903/j.efsa.2023.8442

Espelt, A., Bosque-Prous, M., & Marí-Dell'Olmo, M. (2019). Reflexiones sobre el uso de la Odds Ratio o la Razón de Prevalencias o Proporciones. *Adicciones, 31*(4), 257. https://doi.org/10.20882/adicciones.1416

European Commission. (2023). 2022 annual report- alert and cooperation Network. https://food.ec.europa.eu/system/files/2023-10/acn_annual-report_2022.pdf.

Falzon, L. C., Ogola, J. G., Odinga, C. O., Naboyshchikov, L., Fèvre, E. M., & Berezowski, J. (2021). Electronic data collection to enhance disease surveillance at the slaughterhouse in a smallholder production system. *Scientific Reports, 11*(1). https://doi.org/10.1038/s41598-021-98495-7

FAO. (2024a). Digital environment to support official food safety control during inspections. https://www.fao.org/3/cc7487en/cc7487en.pdf.

FAO. (2024b). Digitalization of the food control system to measure food safety in Georgia. https://www.fao.org/3/cc8008en/cc8008en.pdf.

FAO/WHO. (2013). Principles and guidelines for national food control systems. http://www.fao.orf/food/food-safety-quality/publications-tools/food-safety-publications/en/.

FAO/WHO. (2017). Principles and guidelines for monitoring the performance of national food control systems. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=.

FAO/WHO. (2023). Proposed draft principles and guidelines on the use of remote audit and inspection in regulatory frameworks. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=.

Fernández-Martínez, N. F., Ruiz-Montero, R., Briones, E., Baños, E., García San Miguel Rodríguez-Alarcón, L., Chaves, J. A., Abad, R., Varela, C., & Lorusso, N. (2022). Listeriosis outbreak caused by contaminated stuffed pork, Andalusia, Spain, July to October 2019. *Euro Surveillance, 27*(43). https://doi.org/10.2807/1560-7917.ES.2022.27.43.2200279

Fiocchi, A., Risso, D., DunnGalvin, A., González Díaz, S. N., Monaci, L., Fierro, V., & Ansotegui, I. J. (2021). Food labeling issues for severe food allergic patients. *World Allergy Organization Journal, 14*(10), Article 100598. https://doi.org/10.1016/j.waojou.2021.100598

Firestone, M. J., Eikmeier, D., Scher, D., Medus, C., Hedeen, N., Smith, K., & Hedberg, C. W. (2020). Can aggregated restaurant inspection data help us understand why individual foodborne illness outbreaks occur? *Journal of Food Protection, 83*(5), 788–793. https://doi.org/10.4315/JFP-19-576

Fortin, N. D., Carr, C. C., & Scheffler, J. D. (2021). HACCP and other regulatory approaches to prevention of foodborne diseases. In *Foodborne infections and intoxications* (pp. 545–561). Elsevier. https://doi.org/10.1016/B978-0-12-819519-2.00006-2.

Gallo, M., Ferrara, L., Calogero, A., Montesano, D., & Naviglio, D. (2020). Relationships between food and diseases: What to know to ensure food safety. *Food Research International, 137*, Article 109414. https://doi.org/10.1016/j.foodres.2020.109414

Garrido, V., Vitas, A. I., & García-Jalón, I. (2009). Survey of Listeria monocytogenes in ready-to-eat products: Prevalence by brands and retail establishments for exposure assessment of listeriosis in Northern Spain. *Food Control, 20*(11), 986–991. https://doi.org/10.1016/j.foodcont.2008.11.013

Gawande, A. (2010). *The checklist manifesto: How to get things right*.

Geng, Z., Zhao, S., Tao, G., & Han, Y. (2017). Early warning modeling and analysis based on analytic hierarchy process integrated extreme learning machine (AHP-ELM): Application to food safety. *Food Control, 78*, 33–42. https://doi.org/10.1016/j.foodcont.2017.02.045

Gil, M. I., Truchado, P., Tudela, J. A., & Allende, A. (2024). Environmental monitoring of three fresh-cut processing facilities reveals harborage sites for Listeria monocytogenes. *Food Control, 155*, Article 110093. https://doi.org/10.1016/j.foodcont.2023.110093

Göndöcs, D., & Dörfler, V. (2024). AI in medical diagnosis: AI prediction & human judgment. *Artificial Intelligence in Medicine, 149*, Article 102769. https://doi.org/10.1016/j.artmed.2024.102769

Grau-Noguer, E., Suppi, R., Rodríguez-Sanz, M., Serratosa, J., Bolao, A., Lundén, J., Hau, P., Melo de Vasconcelos, F., Åberg, R., Blomgren, C., Lambert, M., Leppik, K., Vågsholm, I., Kautto, A. H., Lueckl, J., Abeln-Richter, S., Kamphausen, R., Bammens, E., Georgiades, F., … Portaña, S. (2023). Digitalization and official food safety inspections at retail establishments. *Food Control, 154*, Article 109950. https://doi.org/10.1016/j.foodcont.2023.109950

Griffith. (2005). Are we making the most of food safety inspections? A glimpse into the future. *British Food Journal, 107*(3), 132–139. https://doi.org/10.1108/00070700510586452

Grimaldi, D., Collins, C., & Acosta, S. G. (2021). Dynamic restaurants quality mapping using online user reviews. *Smart Cities, 4*(3), 1104–1112. https://doi.org/10.3390/smartcities4030058

Grimes, D. A., & Schulz, K. F. (2008). Making sense of odds and odds ratios. *Obstetrics & Gynecology, 111*(2), 423–426. https://doi.org/10.1097/01.AOG.0000297304.32187.5d

Hazarika, I. (2020). Artificial intelligence: Opportunities and implications for the health workforce. *International Health, 12*(4), 241–245. https://doi.org/10.1093/inthealth/ihaa007

Holah, J. (2024). Hygienic design of food manufacturing infrastructures. In *Encyclopedia of food safety* (pp. 202–217). Elsevier. https://doi.org/10.1016/B978-0-12-822521-9.00162-3.

Hunka, A., Vanacore, E., Medin, I., Gjona, E., & Kautto, A. (2024). Official control in slaughter and game handling: Expectations and prerequisites for implementation of remote meat inspection in Sweden. *Journal of Food Protection, 87*(1), Article 100196. https://doi.org/10.1016/j.jfp.2023.100196

Irwin, K., Ballard, J., Grendon, J., & Kobayashi, J. (1989). Results of routine restaurant inspections can predict outbreaks of foodborne illness: The seattle-king county experience. *American Journal of Public Health, 79*(5), 586–590. https://doi.org/10.2105/AJPH.79.5.586

Kahneman, D., Sibony, O., & Sunstein, C. (2021). *Noise: A flaw in human judgment*. William Collins.

Kase, J. A., Zhang, G., & Chen, Y. (2017). Recent foodborne outbreaks in the United States linked to atypical vehicles — lessons learned. *Current Opinion in Food Science, 18*, 56–63. https://doi.org/10.1016/j.cofs.2017.10.014

Kautto, A. H., Medin, I., Almqvist, V., Boqvist, S., & Vågsholm, I. (2023). Remote ante mortem inspection – Possibilities for improved sustainability in low-capacity slaughter. *Food Control, 153*, Article 109967. https://doi.org/10.1016/j.foodcont.2023.109967

Kim, T. N., Wildey, L., Gleason, B., Bleser, J., Firestone, M. J., Bare, G., Bliss, J., Dewey-Mattia, D., Stueven, H., Brown, L., Dyjack, D., & Hedberg, C. W. (2022). Foodborne outbreak rates associated with restaurant inspection grading and posting at the point of service: Evaluation using national foodborne outbreak surveillance data. *Journal of Food Protection, 85*(7), 1000–1007. https://doi.org/10.4315/JFP-22-007

Kosola, M., Rimhanen-Finne, R., Markkula, A., & Lundén, J. (2023). Association between food control inspection grades and regional incidence of infectious foodborne diseases in Finland. *International Journal of Environmental Health Research*, 1–13. https://doi.org/10.1080/09603123.2023.2183942

Läikkö-Roto, T., Mäkelä, S., Lundén, J., Heikkilä, J., & Nevas, M. (2015). Consistency in inspection processes of food control officials and efficacy of official controls in restaurants in Finland. *Food Control, 57*, 341–350. https://doi.org/10.1016/j.foodcont.2015.03.053

Lyytikäinen, O., Autio, T., Maijala, R., Ruutu, P., Honkanen-Buzalski, T., Miettinen, M., Hatakka, M., Mikkola, J., Anttila, V., Johansson, T., Rantala, L., Aalto, T., Korkeala, H., & Siitonen, A. (2000). An outbreak of *Listeria monocytogenes* serotype 3a infections from butter in Finland. *The Journal of Infectious Diseases, 181*(5), 1838–1841. https://doi.org/10.1086/315453

Martinez, B., Leotti, V., Silva, G., Nunes, L., Machado, G., & Corbellini, L. (2017). Odds ratio or prevalence ratio? An overview of reported statistical methods and appropriateness of interpretations in cross-sectional studies with dichotomous outcomes in veterinary medicine. *Frontiers in Veterinary Science, 4*. https://doi.org/10.3389/fvets.2017.00193

Melkamu, A., Hunka, A., Vanacore, E., Habibi, S., Medin, I., & Kautto, A. (2024). Expert elicitation of remote meat inspection prerequisites in Sweden using best-worst scaling (case 1). *Food Control, 162*, Article 110460. https://doi.org/10.1016/j.foodcont.2024.110460

Miller, H. (1996). The multiple dimensions of information quality. *Information Systems Management, 13*(2), 79–82. https://doi.org/10.1080/10580539608906992

Milos, K., Drosinos, E. H., & Zoiopoulos, P. E. (2017). Factors influencing HACCP implementation in the food industry. *Journal of the Hellenic Veterinary Medical Society, 63*(4), 283. https://doi.org/10.12681/jhvms.15442

Mu, W., Kleter, G. A., Bouzembrak, Y., Dupouy, E., Frewer, L. J., Radwan Al Natour, F. N., & Marvin, H. J. P. (2024). Making food systems more resilient to food safety risks by including artificial intelligence, big data, and internet of things into food safety early warning and emerging risk identification tools. *Comprehensive Reviews in Food Science and Food Safety, 23*(1), 1–18. https://doi.org/10.1111/1541-4337.13296

National Audit Systems Network. (2014). Auditing effectiveness of official control systems. https://www.livsmedelsverket.se/globalassets/foretag-regler-kontroll/vagledningar-kontrollhandbocker/auditing-effectiveness-of-official-control-systems.pdf.

OECD. (2023). Costs, benefits and effectiveness of remote audits for international food safety. https://www.oecd-ilibrary.org/content/paper/fef97106-en.

Pradhan, A. K., Ivanek, R., Gröhn, Y. T., Bukowski, R., Geornaras, I., Sofos, J. N., & Wiedmann, M. (2010). Quantitative risk assessment of listeriosis-associated deaths due to Listeria monocytogenes contamination of deli meats originating from manufacture and retail. *Journal of Food Protection, 73*(4), 620–630. https://doi.org/10.4315/0362-028X-73.4.620

Radu, E., Dima, A., Dobrota, E. M., Badea, A.-M., Madsen, D.Ø., Dobrin, C., & Stanciu, S. (2023). Global trends and research hotspots on HACCP and modern quality management systems in the food industry. *Heliyon, 9*(7), Article e18232. https://doi.org/10.1016/j.heliyon.2023.e18232

Raisch, S., & Krakowski, S. (2021). Artificial intelligence and management: The automation–augmentation paradox. *Academy of Management Review, 46*(1), 192–210. https://doi.org/10.5465/amr.2018.0072

Razak, G. M., Hendry, L. C., & Stevenson, M. (2023). Supply chain traceability: A review of the benefits and its relationship with supply chain resilience. *Production Planning & Control, 34*(11), 1114–1134. https://doi.org/10.1080/09537287.2021.1983661

Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 Laying down the General Principles and Requirements of Food Law, Establishing the European Food Safety Authority and Laying down Procedures in Matters of Food Safety, Official Journal of the European Communities (L31). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:031:0001:0024:EN:PDF.

Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the Hygiene of Foodstuffs, Official Journal of the European Communities (L139). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32004R0852.

Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 Laying down Specific Hygiene Rules for Food of Animal Origin, Official Journal of the European Communities (L139). https://eur-lex.europa.eu/eli/reg/2004/853/oj.

Regulation (EU) No 1169/2011 of the European Parliament and of the Council on the Provision of Food Information to Consumers, Official Journal of the European Union. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:304:0018:0063:en:PDF.

Regulation (EU) No 2017/625 of the European Parliament and of the Council of 15 March 2017 on Official Controls and Other Official Activities Performed to Ensure the Application of Food and Feed Law, Rules on Animal Health and Welfare, Plant Health and Plant Protection Products, L 95 Official Journal of the European Union (L95). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0625&from=ES.

Schiaffino, A., Rodríguez, M., Pasarín, M. I., Regidor, E., Borrell, C., & Fernández, E. (2003). ¿Odds ratio o razón de proporciones? Su utilización en estudios transversales. *Gaceta Sanitaria, 17*(1), 70–74. https://doi.org/10.1016/S0213-9111(03)71694-X

Simmons, C. K., & Wiedmann, M. (2018). Identification and classification of sampling sites for pathogen environmental monitoring programs for Listeria monocytogenes: Results from an expert elicitation. *Food Microbiology, 75*, 2–17. https://doi.org/10.1016/j.fm.2017.07.005

Soon, J. M., Brazier, A. K. M., & Wallace, C. A. (2020). Determining common contributory factors in food safety incidents – a review of global outbreaks and recalls 2008–2018. *Trends in Food Science & Technology, 97*, 76–87. https://doi.org/10.1016/j.tifs.2019.12.030

Spanish Agency for Food Safety and Nutrition. (2022). Annual report 2021- Multi-annual national control plan 2021-2025. https://www.aesan.gob.es/AECOSAN/docs/documentos/seguridad_alimentaria/pncoca/INFORME_ANUAL_ESPANA_2021.pdf.

Strong, D. M., Lee, Y. W., & Wang, R. Y. (1997). Data quality in context. *Communications of the ACM, 40*(5), 103–110. https://doi.org/10.1145/253769.253804

Taylor, E. (2001). HACCP in small companies: Benefit or burden? *Food Control, 12*(4), 217–222. https://doi.org/10.1016/S0956-7135(00)00043-8

Thakkar, S., Slikker, W., Yiannas, F., Silva, P., Blais, B., Chng, K. R., Liu, Z., Adholeya, A., Pappalardo, F., Soares, M. da L. C., Beeler, P. E., Whelan, M., Roberts, R., Borlak, J., Hugas, M., Torrecilla-Salinas, C., Girard, P., Diamond, M. C., Verloo, D., … Tong, W. (2023). Artificial intelligence and real-world data for drug and food safety – a regulatory science perspective. *Regulatory Toxicology and Pharmacology, 140*, Article 105388. https://doi.org/10.1016/j.yrtph.2023.105388

Thomas, J., Govender, N., McCarthy, K. M., Erasmus, L. K., Doyle, T. J., Allam, M., Ismail, A., Ramalwa, N., Sekwadi, P., Ntshoe, G., Shonhiwa, A., Essel, V., Tau, N., Smouse, S., Ngomane, H. M., Disenyeng, B., Page, N. A., Govender, N. P., Duse, A. G., … Blumberg, L. H. (2020). Outbreak of listeriosis in South Africa associated with processed meat. *New England Journal of Medicine, 382*(7), 632–643. https://doi.org/10.1056/NEJMoa1907462

Thompson, M. L., Myers, J. E., & Kriebel, D. (1998). Prevalence odds ratio or prevalence ratio in the analysis of cross sectional data: What is to be done? *Occupational and Environmental Medicine, 55*(4), 272–277. https://doi.org/10.1136/oem.55.4.272

van der Voort, H., van Bulderen, S., Cunningham, S., & Janssen, M. (2021). Data science as knowledge creation a framework for synergies between data analysts and domain professionals. *Technological Forecasting and Social Change, 173*, Article 121160. https://doi.org/10.1016/j.techfore.2021.121160

Van Houdt, R., & Michiels, C. W. (2010). Biofilm formation and the food industry, a focus on the bacterial outer surface. *Journal of Applied Microbiology, 109*(4), 1117–1131. https://doi.org/10.1111/j.1365-2672.2010.04756.x

Wang, X., Bouzembrak, Y., Lansink, A. O., & van der Fels-Klerx, H. J. (2022). Application of machine learning to the monitoring and prediction of food safety: A review. *Comprehensive Reviews in Food Science and Food Safety, 21*(1), 416–434. https://doi.org/10.1111/1541-4337.12868

Yahata, Y., Misaki, T., Ishida, Y., Nagira, M., Watahiki, M., Isobe, J., Terajima, J., Iyoda, S., Mitobe, J., Ohnishi, M., Sata, T., Taniguchi, K., Tada, Y., & Okabe, N. (2015). Epidemiological analysis of a large enterohaemorrhagic Escherichia coli O111 outbreak in Japan associated with haemolytic uraemic syndrome and acute encephalopathy. *Epidemiology and Infection, 143*(13), 2721–2732. https://doi.org/10.1017/S0950268814003641

Yapp, C., & Fairman, R. (2006). Factors affecting food safety compliance within small and medium-sized enterprises: Implications for regulatory and enforcement strategies. *Food Control, 17*(1), 42–51. https://doi.org/10.1016/j.foodcont.2004.08.007

Zacharski, K. A., Southern, M., Ryan, A., & Adley, C. C. (2018). Evaluation of an environmental monitoring program for the microbial safety of air and surfaces in a dairy plant environment. *Journal of Food Protection, 81*(7), 1108–1116. https://doi.org/10.4315/0362-028X.JFP-17-464

Zarei, M., Rahimi, S., Fazlara, A., & Anvari, S. E. (2023). High biofilm-forming Pseudomonas strains isolated from poultry slaughterhouse surfaces: Their importance in the persistence of Salmonella enteritidis in slaughterhouses. *International Journal of Food Microbiology, 390*, Article 110126. https://doi.org/10.1016/j.ijfoodmicro.2023.110126

Zhe Jin, G., & Lee, J. (2014). Inspection technology, detection, and compliance: Evidence from Florida restaurant inspections. *Journal of Economics, 45*(4), 885–917. https://doi.org/10.1111/1756-2171.12074

Zocchetti, C., Consonni, D., & Bertazzi, P. A. (1997). Relationship between prevalence rate ratios and odds ratios in cross-sectional studies. *International Journal of Epidemiology, 26*(1), 220–223. https://doi.org/10.1093/ije/26.1.220