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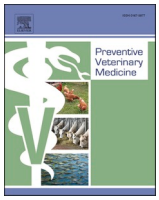

Biosecurity implementation on large-scale poultry farms in Europe: A qualitative interview study with farmers

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ABSTRACT

Biosecurity is an essential tool for rearing healthy animals. Biosecurity measures (BMs) are well known in poultry production, but it is difficult to assess actual implementation on farms. The aims of this qualitative study were (1) to provide an overview of biosecurity implementation according to poultry farmers in Europe; and (2) to better understand the reported reasons and potential obstacles for not implementing the measures. In seven European Union Member States, 192 farmers (118 under contract with a company and 68 independents) working in seven different categories of poultry production were interviewed on 62 BMs to determine the frequency of implementation and the reasons for non-implementation. Most of the replies (n = 7791) concerning BM implementation were reported by the farmers as "always" implemented (81%), statistically higher for breeders (87%) and layers (82%) and lower for independent farms *versus* farms under contract with a company (79.5% and 82.5%, respectively). Regardless the poultry production category, the most frequently implemented BMs declared by the farmers were daily surveillance of birds, rodent control and feed storage protection. Standard hygiene practices were also mentioned as high-implementation measures for most production categories, with some deficiencies, such as rendering tank disinfection after each collection and, for meat poultry, disinfection of the feed silo and bacterial control of house cleaning and disinfection between each cycle. The entry of vehicles and individuals onto poultry farms, especially during critical points of eggs collection for breeders and layers, as well as the presence of other animals, such as the "all in/all out" practice, particularly in layers and ducks, were also reported as the least commonly practiced measures. The main reasons for not implementing the measures (n = 1683 replies) were low awareness and poor knowledge of the expected benefits of biosecurity ("no known advantages" 14%, and "not useful" 12%), the lack of training ("not enough training" 5% and "advice" 7%), lack of time (19%), and financial aspects (17%). Despite the good overall biosecurity mentioned by the farmers, these findings highlight certain deficiencies, suggesting room for improvement and the need for targeted and tailored support of poultry farmers in Europe.

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1. Introduction

Poultry farming in Europe has recently been significantly affected by successive highly pathogenic avian influenza (HPAI) crises (EFSA Journal, 2023) that emphasize the need to enhance the prevention and control of animal diseases at the European level. At more than 13.4 million tons produced annually, the European Union (EU) is one of the world's largest producers of poultry meat (https://agriculture.ec.europa.eu). The market is characterized by expansion of trade in food and animals, and globalization of European commercial exchanges. In this context, the spread of transmissible poultry diseases can lead to devastating economic and social consequences. The Council of the EU recently stressed the key role played by biosecurity in reducing the risk of animal diseases at farm level, with an integrated approach within the European Union (Council EU, 2019) based on cooperation and coordination between the Member States to prevent the introduction and spread of animal diseases within EU territory. Biosecurity is a crucial preventive tool to reduce the risk of introduction of animal diseases (external biosecurity), as well as their establishment and spread (internal biosecurity) from and within an animal production site (Regulation (EU) 2016/429; Gelaude et al., 2014; OIE, 2019). Adopting suitable biosecurity measures decreases the risk of pathogen contamination on poultry farms, particularly avian influenza virus (Duvauchelle et al., 2013; Ssematimba et al., 2013; Guinat et al., 2020) and food-borne zoonotic agents, *e.g.*, *Salmonella* spp. (Huneau-Salaün et al., 2009; Snow et al., 2010) and *Campylobacter* spp. (Hald et al., 2000), but also could reduce the consumption of antimicrobials (Chauvin et al., 2005; Dhaka et al., 2023). Biosecurity practices and their expected benefits are well known; however, several studies have reported suboptimal application of biosecurity on poultry farms, for instance entry of personnel or visitors (Racicot et al., 2011; Van Steenwinkel et al., 2011), management of the hygiene lock (Delpont et al., 2021a; Tilli et al., 2022), vehicle flows and depopulation (Van Limbergen et al., 2018). Given this situation, the challenge of better understanding why some well-known biosecurity measures are partially applied or not applied by poultry producers must be considered. The factors determining the application of biosecurity are complex and involve both technical, economic, and psychosocial factors. Various determinants associated with poor biosecurity compliance on poultry farms have been reported, such as lack of training on why biosecurity is needed (Vaillancourt and Carver, 1998), economic constraints (Vaillancourt and Carver, 1998), lack of knowledge on biosecurity and animal disease transmission (Cui and Liu, 2016; Delpont et al., 2021b), but also certain personality traits relative to responsibility or conscientiousness (Delpont et al., 2021b). Despite the fundamental importance of biosecurity, there is a paucity of information on the overall application of biosecurity measures on poultry farms in Europe, with previous studies specifically designed in the context of a given poultry disease (Cui and Liu, 2016; Delpont et al., 2021b), either in one country (Gelaude et al., 2014; Delpont et al., 2021a; Tilli et al., 2022) or in a single poultry production (Van Limbergen et al., 2018). Given the huge diversity in European poultry farming practices, with broad commercial exchanges, a common approach is needed to better assess the implementation of biosecurity on farms and to ensure that the European poultry sector is safe and sustainable.

In this context, the objectives of our study, carried out within the H2020 NETPOULSAFE project, coordinated by the French Technical Institute of Poultry Farming, Rabbit Farming, and Aquaculture (ITAVI) and bringing together seven European countries (Belgium, France, Hungary, Italy, Netherlands, Poland, and Spain) were, from the farmers point of view (1) to provide an overview of the implementation of biosecurity as declared by the farmers, and (2) to understand the reasons for, and the potential obstacles and barriers to, non-implementation of biosecurity measures. Identifying the difficulties encountered by farmers will make it possible to develop adapted and tailored supporting measures to improve biosecurity compliance on poultry farms.

2. Materials and methods

2.1. Poultry farm selection

The poultry farms were sampled in each participating country by the national NF (Network Facilitator) in accordance with a common selection method. The study was not designed to be representative of poultry production or to compare countries. The sampling objective here was to collect field opinions on the implementation of the biosecurity measures while taking into account the wide diversity of the poultry production categories and farming systems at European level, which explains the sampling method and the limited size per country and production category. A minimum of four poultry production categories was included from each participating country and the enclosed broiler and enclosed layer production categories were mandatory. In order to account for the diversity of poultry farming in Europe, the choice of other production categories (breeders, enclosed turkeys and ducks, and free-range broilers, layers and ducks) was free, as was the farm size and financial model (*i.e.* independent or under contract with a company), depending on the national specificities and feasibility in each participating country. The farms had to best reflect the national production profile for their country. For each poultry production category, five farmers were chosen by the NF, based on their experience and knowledge of the poultry sectors in their country, ensuring proper selection. Farmers were also chosen on the basis of their willingness to participate in the study.

2.2. Data collection

The questionnaire for farmers included 62 biosecurity measures (BMs) (36 internal and 26 external measures). The first section was common to all poultry production categories and included 26 external BMs in the items "Animal production on the site", "Structure and circulation on the site", "Personnel, visitors or teams", "Poultry at arrival", "Feed and drinking water", "Biological vectors control", "Management of poultry manure", "Management of dead animals" and 12 Internal BMs in the items "Structure and circulation in the poultry house", "Management of material or litter in the poultry house", "Cleaning and disinfection of the house and material" and "Management of poultry". Specific sections were also designated to the different categories of poultry production, free-range (with nine Internal BMs in the item "Management of the free-range area"), breeders (with eight internal BMs in the item "Management of hatching eggs") and layers (with seven internal BMs in the item "Management of laying eggs"). Three questions were asked regarding (1) implementation or non-implementation of the measure (always, sometimes, never, other frequency, unknown); (2) the reasons for not implementing the measure, with multiple answers possible (takes too much time, too expensive, not adapted to the farm, no known advantages, not useful, not enough training, not enough advice, other reason and unknown); and (3) the farmer's opinion on the efficiency of the non-implemented measures (efficient, moderately efficient, not efficient, other opinion, unknown). This study was designed like an interview study based on the farmers' declarations regarding the implementation of biosecurity measures (reported facilities and practices). Additionally, farm characteristics like farmer's gender and age, farm capacity (number of birds) and farming systems (independent for direct sale or under contact with a company) were also collected. The questionnaire is available in Supplementary data 1. Data collection in each country took place between April and September 2021, mainly by one person per country (the national network facilitator, NF), who received prior training on standardized data collection. Most of the interviews were conducted in person during a farm visit. However, due to visitor entry restrictions during avian influenza epidemics and the Covid-19 pandemic, 22% of the interviews were conducted by telephone / in online meetings (mainly in Spain, France and Netherlands).

2.3. Data analysis

Collected data were entered into Sphynx® software by each national NF, following which the overall database was exported in Excel 2016 and analyzed with R-4.0.2 software (R foundation, Vienna, Austria). A preliminary phase of verification and cleaning of the database was carried out to check for missing or potentially incoherent data. An overall descriptive analysis of all the collected answers (*e.g.*, implementation, reason, and efficiency) was performed. For each poultry production category, we focused on the 10 most commonly implemented BMs reported (the 10 BM's with the highest "always implemented" percentages in each category) and the 10 least commonly implemented BMs reported (the 10 BM's with the lowest "always implemented" percentages in each category), along with the reasons mentioned by the farmers for non-implementation. The aim was to highlight the key points for the application of biosecurity measures as declared by the farmers. Analysis of the statistical association between the implementation of biosecurity reported by farmers and farm characteristics (*i.e.*, type of production, farming system, farm size, and farmer age and gender) was also performed with univariate analysis using Pearson's Chi-squared test or Student's t-test, considering a significant difference with $p < 0.05$.

3. Results

3.1. Poultry farm characteristics

A total of 192 farmer interviews were performed, in the following production categories: 46 breeders, 32 enclosed broilers, 24 enclosed ducks, 37 enclosed layers, 27 enclosed turkeys, 21 free-range layers, and five free-range meat poultry (Table 1). The farm characteristics are shown in Table 2. Among the interviewed farmers, most were men (78%), and ages were mostly between 35 and 55 years (60%). This farmer profile was observed across the different poultry production categories. The overall mean capacity of the poultry productions was 54,194 (standard deviation (SD) 98,736) birds, with a higher capacity in enclosed broilers 118,643 (SD 170,688), and enclosed layers 94,382 (SD 132,203), showing diverse farm sizes. Regarding the farming system, 37% of farms were independent *vs* 63% under contract with a company. Both farming systems were found in each of the seven production categories. Fewer independent farmers in enclosed broilers (19%) and turkeys (8%) were included compared to the other productions, such as 68% in free-range layers.

3.2. Most commonly implemented biosecurity measures

Analysis of all the farmers' responses (n = 7791), regarding the implementation of BMs showed the following: "always" (81%), "sometimes" (5%), and "never" (12%) (Fig. 1a). Regardless of the poultry production category, most of the farmers declared that BMs were always implemented on their farms with a frequency higher than 80% for egg production (breeders, and enclosed and free-range layers) and slightly lower than 80% for meat production (both enclosed and free-range). The meat poultry production category included broiler, turkey and duck farms. A statistically significant difference was noted between the breeders (87%) and all the other production systems ($p < 0.001$) (82% to 73%, for enclosed layers and free-range meat poultry, respectively), and between the layers (enclosed and free-range) (81%) *vs* meat production category ($p < 0.04$). In the meat production category, the only significant difference was the frequency in enclosed ducks, which was significantly lower (p = 0.02) than the enclosed broilers (74% *vs* 79%, respectively).

Farmers reported the internal BMs and the external BMs as always implemented, in 82% and 81% of the collected answers respectively (not statistically significant). Table 3 shows the BMs that farmers most commonly declared as being implemented (considering the top 10 BMs with highest % of "always implemented" in each poultry production category). The surveillance of poultry ("register for flocks BM15" and "daily surveillance with clinical alert criteria BM38") and certain standard hygiene practices ("feed storage protection BM17" and "rodent control BM19") were reported as the most common applied measures in all surveyed poultry production categories. Other standard hygiene practices were also reported in the top 10 BMs for most of the productions ("secured manure storage BM22", "presence of a closed rendering tank BM24" and "cleaning/disinfection between each flock of the house, the materials and water pipelines BM31-BM32-BM33"). The BMs regarding visitors were also mentioned by the farmers as commonly implemented in several production categories ("register for visitors and teams BM10", "specific clothes/shoes before entering the house for visitors BM11-BM12" and "specific clothes/shoes if chick deliverer enters the house BM16"). Finally, given the specificities of the free-range and egg production farms, similar BMs were reported to be the most commonly implemented for free-range poultry ("period of sanitary downtime in the free-range area BM47") and for the breeders and layers ("traceability of eggs BM49-BM57" and "specific egg sorting and storage rooms BM51-BM58").

3.3. Biosecurity measures least commonly implemented

Even though the overall analysis of all collected answers showed that most BMs are reported by the farmers as "always" implemented (81%) on the farms, deficiencies were noted regarding certain BMs, shown in Table 4 (considering the 10 BMs with the lowest % of "always implemented" in each poultry production category). Certain BMs or groups of BMs in the top 10 least implemented are mentioned by the farmers for all the surveyed poultry production categories: "wheel dips for vehicles disinfection BM05", measures related to entry of personnel or visitors ("clothes/hand washing BM06-BM08", "showering before entering the house BM09-BM14", "clothes/shoes for the operators in egg collection BM53-BM60"), and related to the presence of other animals on the site ("all in/all out BM01", "sanitary barriers if other animal production BM03" and "domestic animals on the site BM21"). Some critical hygiene points were also mentioned as less commonly implemented by the farmers including "rendering tank cleaning/disinfection BM26" for most of the production categories, and "cleaning/disinfection of the feed silo BM34" and "bacterial control of disinfection of the house BM 35" in

Table 1
Distribution of the farmers sample for each poultry production category and country (n = 192).

	Country							Total
Production	**Belgium**	**Spain**	**France**	**Hungary**	**Italy**	**Netherlands**	**Poland**	
Breeders	4	3		23	3	3	10	46
Enclosed layers	5	5	5	5	6	5	6	37
Free-range layers	3	5	5		3	5		21
Enclosed broilers	5	5	5	3	5	4	5	32
Enclosed ducks		3	5	9	3	4		24
Enclosed turkeys	3	3	5	4	7		5	27
Free-range meat poultries					3	2		5
Total	**20**	**24**	**25**	**44**	**30**	**23**	**26**	**192**

Table 2
Farm characteristics for each poultry production category (n = 192).

	Farmers					Farm capacity	Farming system	
	Gender		Age					
	Woman	**Man**	**< 35**	**35-55**	**> 55**	**Mean number of birds ± SD Min-max Median**	**Independent**	**Under contract**
Breeders (n = 46)	10 (22%)	36 (78%)	5 (11%)	37 (80%)	4 (9%)	31 727 ± 24 506 3 000-100 000 22 850	18 (40%)	27 (60%)
Enclosed layers (n = 37)	9 (24%)	28 (76%)	9 (24%)	17 (46%)	11 (30%)	94 382 ± 132 203 300-777 600 46 214	17 (49%)	18 (51%)
Free range layers (n = 21)	7 (33%)	14 (67%)	3 (14%)	13 (62%)	5 (24%)	23 363 ± 20 176 800-70 000 15 000	13 (68%)	6 (32%)
Enclosed broilers (n = 32)	7 (22%)	25 (78%)	8 (25%)	15 (47%)	9 (28%)	118 643 ± 170 688 3 000-750 000 82 000	6 (19%)	26 (81%)
Enclosed ducks (n = 24)	2 (8%)	22 (92%)	5 (21%)	14 (58%)	5 (21%)	15 374 ± 12 034 1 280-41 000 11 400	10 (42%)	14 (68%)
Enclosed turkeys (n = 27)	7 (26%)	20 (74%)	3 (11%)	15 (56%)	9 (33%)	27 794 ± 25 735 5 000-140 000 20 000	2 (8%)	24 (92%)
Free-range meat poultries (n = 5)	0	5 (100%)	0	4 (80%)	1 (20%)	23 700 ± 14 347 10 000-45 000 20 500	2 (40%)	3 (60%)
All categories (n = 192)	42 (22%)	150 (78%)	33 (17%)	115 (60%)	44 (23%)	54 194 ± 98 736 300-777 600 29 000	68 (37%)	118 (63%)

meat production category. Other hygiene points were reported to be less commonly implemented, especially in the enclosed ducks and free-range meat poultry ("disinfection of the house and water pipeline between each flock BM31-BM33", "water analysis BM18", "sanitary downtime less than 15 days BM36", area delimitation with "professional secured area BM04" and "hygiene lock BM28"). Finally, given the specificities of free-range and egg production, similar less commonly implemented BMs were reported in breeders and layers regarding the management of eggs (with BMs in Item I5) and for free-range poultry with "protection of the outside area with a net BM44".

3.4. Reasons associated with the least commonly implemented biosecurity measures

Based on an analysis of all the collected replies, the reasons the farmers gave for not always implementing measures (n = 1683) varied (Fig. 1b): "takes too much time" (19%), "too expensive" (17%), "not adapted to the farm"(19%), "no known advantages" (14%), "not useful" (12%), "not enough training" (7%) and "not enough advice" (5%). The farmers also seem to question the effectiveness of these measures, given that they reported them as "not efficient" (Fig. 1c) in 35% of the replies (n = 1290). Considering the different poultry production categories, the reply "not adapted to the farm" was more frequently reported in free-range, with 33% and 37% of the replies collected in free-range layers and free-range meat poultry, respectively. For some BMs reported in the top 10 least implemented by the farmers (Fig. 2), several common reasons were more frequently mentioned. "Too time-consuming" was reported for the measures related to entry of personnel or visitors to the house ("specific clothes BM06", "hand washing BM08" and "showering by personnel and visitors BM09-BM14") and to the vehicles entering the farm ("wheel dip disinfection BM05"). The farmers mentioned costs mainly for material management ("separate material for the poultry house BM 29"), the laboratory analysis ("drinking water analysis BM18" and "bacterial control of the cleaning/disinfection of the house BM 35") and the "sanitary downtime BM36". The reason "not adapted to the farm" was more frequently reported for BMs related to organization of production ("all in/all out BM01") and to structural characteristics ("delimitation of a professional secured area BM04", "hygiene lock with separate zones BM 28", "protective net on the free-range area BM44", "specific entrance for egg collection BM52-BM59" and "different personnel between poultry room and eggs room BM55-BM62"). Finally, the farmers mentioned "no known advantages" particularly for "domestic animals on the site BM21" and "feed silo cleaning and disinfection BM34", and the lack of advice/training for "hand washing before entering the house BM08" and "cleaning/disinfection of the rendering tank after each collection BM26". Supplementary data 2 provides detailed reasons for the 10 BMS that were least commonly declared as being implemented, considering each poultry production category.

3.5. Influence of farm characteristics

The gender of the respondents did not significantly affect the farmers' answers on the implementation of the BMs (replies of "always implemented" for 81.2% and 80.8% of men and women, respectively). Farmer age significantly influenced responses, with a higher % of measures reported always implemented in the category 35–55 years of age (83%) *vs* 80% for farmers < 35 years of age ($p < 0.01$), and 77% for those > 55 years of age ($p < 0.001$). Reports of lower BM implementation levels for the entry of personnel were noted for farmers > 55 years of age compared to the other two age categories, but the difference was statistically significant only with the 35–55 years of age group ($p < 0.01$) ("specific clothes BM06" 59% *vs* 82%, "specific shoes BM07" 77% *vs* 93%, "hand washing BM08" 59% *vs* 83%). For visitor entry, lower reported implementation was observed for farmers < 35 years of age compared to the other two categories, but the difference was only statistically significant with the 35–55 years of age group ($p < 0.01$) ("register BM10" 81% *vs* 97%, "specific clothes BM11" 79% *vs* 96%, "specific shoes BM12" 82% *vs* 97%, "hand washing BM13" 70% *vs* 90%). Showering, both for personnel and visitors was reported as less commonly implemented for farmers > 55 years of age *vs* the other categories, and statistically significantly different with the farmers < 35 years of age for personnel (5% *vs* 41%), and with 35–55 years of age for visitors (11% *vs* 34%).

The farming system was also significantly associated with the

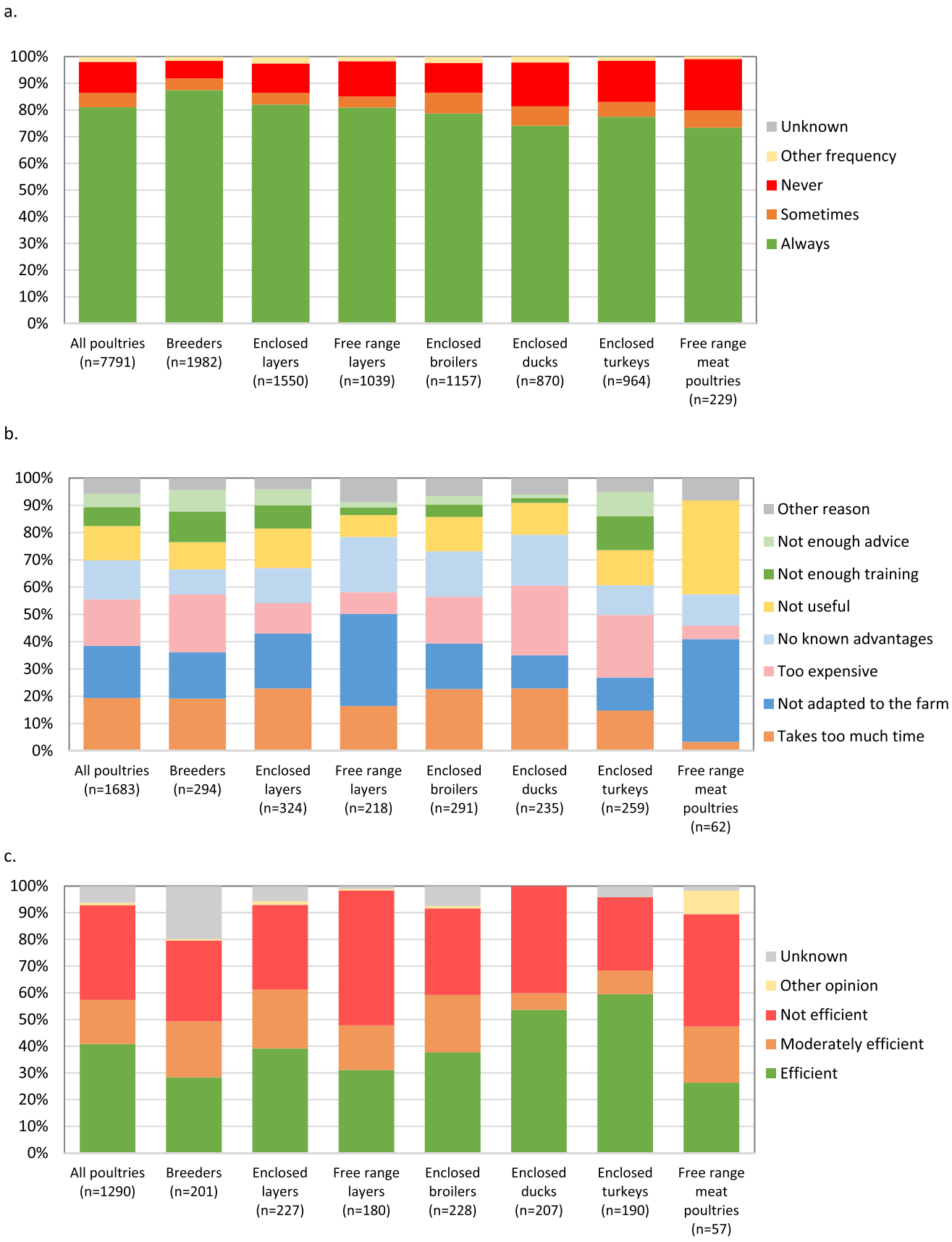

Fig. 1. Distribution of all replies given by farmers (n = 192) on the implementation of the 62 BMs (1a), the reasons for not implementing the measures (1b), and the farmer's opinion on the efficiency of the non-implemented measures (1c) considering all poultry production categories and each category.

Table 3
Distribution of the 10 BMs declared as most commonly implemented in each production category with the highest % ("always implemented") highlighted in grey***.

			Breeders		Enclosed layers		Free-range layers		Enclosed broilers		Enclosed ducks		Enclosed turkeys		Free-range meat		Number of BM+ **
Item	BM No.	Description of BM	%	n*	%	n*	%	n*	%	n*	%	n*	%	n*	%	n*	
E1 - Animal production on site	BM02	No backyard on the site	95.7	46	81.1	37	95.2	21	87.5	32	95.8	24	100.0	26	80.0	5	2
	BM03	If other animal production on the site sanitary barriers with poultry	84.4	32	64.3	14	90.0	10	100.0	13	58.3	12	84.6	13	50.0	2	1
E3 - Personnel, visitors or teams	BM10	Register for visitors and teams	97.8	46	97.3	37	100.0	21	84.4	32	95.7	23	88.9	27	100.0	5	4
	BM11	Specific clothes for visitors before entering the house	97.8	46	94.6	37	95.2	21	90.6	32	83.3	24	85.2	27	100.0	5	1
	BM12	Specific shoes for visitors before entering the house	97.8	46	97.3	37	95.2	21	90.6	32	87.5	24	88.9	27	100.0	5	2
E4 - Poultry at arrival	BM15	Register for the flock	100.0	46	100.0	37	100.0	21	100.0	32	100.0	24	100.0	27	100.0	4	7
	BM16	If the chick deliverer enters the house: specific clothes and shoes	100.0	40	76.9	26	86.7	15	100.0	19	100.0	18	76.9	13	100.0	3	4
E5 - Feed and drinking water	BM17	Feed storage protection	100.0	46	100.0	37	100.0	21	100.0	32	100.0	23	96.3	27	100.0	5	7
E6 - Biological vector control	BM19	Rodent control	100.0	46	100.0	37	100.0	21	100.0	32	100.0	24	92.6	27	100.0	5	7
E7 - Management of poultry manure	BM22	Manure stored in a specific isolated area outside of the secured professional area	88.2	34	89.7	29	81.3	16	88.9	18	94.7	19	94.7	19	100.0	5	3
	BM24	Presence of a closed and protected rendering tank	100.0	46	100.0	36	100.0	20	96.8	31	91.3	23	83.3	24	100.0	5	5
I1 - Structure and circulation in poultry house	BM28	Hygiene lock with 2 separate zones	82.6	46	91.9	37	95.2	21	87.5	32	100.0	24	77.8	27	60.0	5	1
I3 - Cleaning and disinfection of house and material	BM31	Cleaning and disinfection of the house between each flock	100.0	46	97.3	37	100.0	21	100.0	32	75.0	24	100.0	27	60.0	5	5
	BM32	Cleaning and disinfection of the material between each flock	100.0	46	97.3	37	100.0	21	100.0	32	79.2	24	100.0	27	80.0	5	5
	BM33	Cleaning and disinfection of the drinking water pipeline between each flock	97.8	46	94.6	37	100.0	20	100.0	32	62.5	24	96.3	27	60.0	5	3
I5 - Management of poultry	BM37	Vaccination protocol of each poultry flock	100.0	44	97.1	34	100.0	18	96.7	30	95.0	20	96.3	27	80.0	5	4
	BM38	Daily surveillance with clinical alert criteria	100.0	46	100.0	37	100.0	21	100.0	32	100.0	24	100.0	27	100.0	5	7
I4 - Management of free-range area	BM47	Period of sanitary downtime in the free-range area					100.0	21							100.0	5	2
I5 - Management of eggs	BM49-BM57	Traceability of the eggs	100.0	36	100.0	35	100.0	18									3
	BM51-BM58	Specific eggs sorting and storage rooms	100.0	36	100.0	31	100.0	14									3

BM: Biosecurity Measure Item E: external Item I: internal
* Number of replies * * number of production categories for which a BM is declared as being among the 10 most implemented (designated by BM+). * ** It is possible to have more than 10 BMs in cases with similar percentages

Table 4
Distribution of the 10 BMs declared as least commonly implemented in each production category with the lowest % ("always implemented") highlighted in grey ***.

			Breeders		Enclosed layers		Free-range layers		Enclosed broilers		Enclosed ducks		Enclosed turkeys		Free-range meat		Number of BM- **
Item	BM No.	Description of BM	%	n*	%	n*	%	n*	%	n*	%	n*	%	n*	%	n*	
E1 - Animal production on site	BM01	"all-in/all-out" poultry production on the site	93.5	46	64.9	37	52.4	21	90.6	32	54.2	24	85.2	27	60.0	5	4
	BM03	If other animal production on the site sanitary barriers with poultry	84.4	32	64.3	14	90.0	10	100.0	13	58.3	12	84.6	13	50.0	2	3
E2 - Structure and circulation on site	BM04	Delimitation with a barrier or closure of a professional secured area with only necessary vehicles to the poultry house	87.0	46	83.8	37	76.2	21	81.3	32	58.3	24	88.9	27	80.0	5	1
	BM05	Wheel dips for disinfection of the vehicles or pulverization before entering the site	78.3	46	59.5	37	61.9	21	68.8	32	62.5	24	66.7	27	60.0	5	7
E3 - Personnel, visitors or teams	BM06	Specific clothes for personnel before entering the house	84.8	46	81.1	37	66.7	21	68.8	32	83.3	24	70.4	27	60.0	5	4
	BM08	Washing of hands for personnel before entering the house	89.1	46	75.0	36	71.4	21	65.6	32	83.3	24	61.5	26	80.0	5	2
	BM09	Showering for personnel before entering the house	65.2	46	10.8	37	19.0	21	9.4	32	25.0	24	11.5	26	0.0	5	7
	BM14	Showering for visitors before entering the house	71.7	46	24.3	37	23.8	21	9.4	32	8.3	24	7.7	26	0.0	5	7
E5 - Feed and drinking water	BM18	Drinking water analysis end line each year	87.0	46	78.4	37	90.0	20	81.3	32	62.5	24	80.8	26	80.0	5	1
E6 - Biological vector control	BM21	No domestic animals on the site	75.6	45	70.3	37	90.5	21	62.5	32	66.7	24	59.3	27	20.0	5	4
E8 - Management of dead animals	BM23	Removal of carcasses at least twice a day	95.7	46	59.5	37	71.4	21	90.6	32	83.3	24	88.9	27	100.0	5	1
	BM26	Cleaning and disinfection of the rendering tank after each collection	45.7	46	66.7	36	42.1	19	61.3	31	78.3	23	66.7	24	80.0	5	5
I1 - Structure and circulation in poultry house	BM28	Hygiene lock with 2 separate zones	82.6	46	91.9	37	95.2	21	87.5	32	100.0	24	77.8	27	60.0	5	1
I2 - Management of material or litter in poultry house	BM29	Recognizable separate material only for the poultry house	89.1	46	89.2	37	85.7	21	65.6	32	70.8	24	70.4	27	80.0	5	2
	BM30	Protection of litter	97.4	38	100.0	15	100.0	10	83.3	24	93.8	16	64.7	17	60.0	5	2
I3 - Cleaning and disinfection of house and material	BM31	Cleaning and disinfection of the house between each flock	100.0	46	97.3	37	100.0	21	100.0	32	75.0	24	100.0	27	60.0	5	1
	BM33	Cleaning and disinfection of the drinking water pipeline between each flock	97.8	46	94.6	37	100.0	20	100.0	32	62.5	24	96.3	27	60.0	5	2
	BM34	Cleaning and disinfection of the feed silo between each flock	95.7	46	77.1	35	75.0	20	50.0	32	20.8	24	55.6	27	20.0	5	4
	BM35	Bacterial autocontrol of the cleaning and disinfection of the house between each flock	80.4	46	75.7	37	71.4	21	40.6	32	16.7	24	22.2	27	0.0	5	4
	BM36	Period of the sanitary downtime > 15 days between each flock	91.1	45	94.6	37	85.7	21	53.1	32	36.4	22	85.2	27	60.0	5	3
I4 - Management of the free-range area	BM44	Protective net on the free-range area					5.0	20							0.0	5	2
I5 - Management of eggs	BM50	Hatching eggs disinfection on the farm	40.0	35													1
	BM52-BM59	Specific entrance for the collection of eggs by the driver	77.1	35	78.6	28	100.0	11									1
	BM53-BM60	If the driver enters storage rooms for the collection of eggs: specific clothes and shoes	75.0	28	66.7	27	55.6	9									3
	BM54-BM61	Cleaning and disinfection of the storage room after each collection	47.2	36	63.3	30	69.2	13									3
	BM55-BM62	Different personnel between the poultry room and the egg sorting and storage rooms	19.4	36	35.5	31	21.4	14									3

BM: Biosecurity Measure Item E: external Item I: internal
* Number of replies * * number of production categories for which a BM is declared as being among the 10 least implemented (designated by BM-). * ** It is possible to have more than 10 BMs in cases with similar percentages

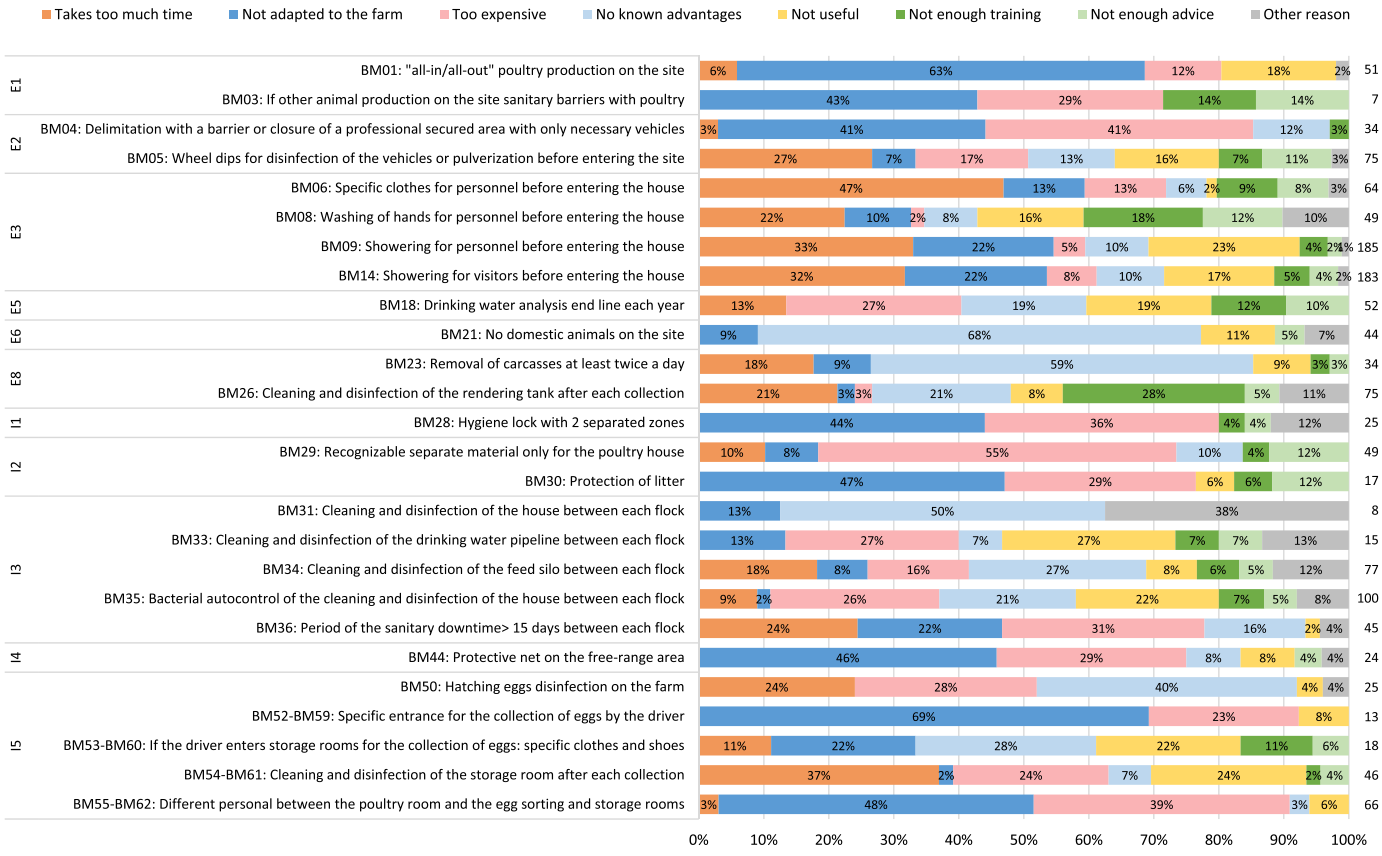

Fig. 2. Distribution of the reasons reported by farmers for non-implementation of the least commonly implemented BMs on farms.

implementation biosecurity level reported, with a better percentage of "always implemented" for farms under contract with a company, 82.5% *vs* 79.5% for independent farms. Considering each poultry production category, a significant difference was noted in three production categories between farmers under contract *vs* independent: enclosed ducks (78% *vs* 68%, $p < 0.001$), free-range layers (85% *vs* 79% p = 0.04) and free-range meat poultry (83% *vs* 58%, $p < 0.001$). In these production categories, three BMs were statistically less commonly reported as implemented on independent farms *vs* those under contract: "all in/all out BM01" (28% *vs* 78%), "specific shoes BM 07" (68% *vs* 100%), and "hand washing BM 08" (64% *vs* 96%). Regarding farm size, no statistically significant associations were found between the implementation of biosecurity reported by the farmers and production capacity.

4. Discussion

This study provided a better understanding of farmers' perception of biosecurity and the obstacles they may encounter in the application of biosecurity measures, considering the wide variety of poultry production systems in Europe. As planned in the sampling design, a minimum of four poultry production categories were included in each country. Enclosed broilers and layers, the main productions in the European Union poultry sector, were systematically surveyed in all the countries, and the other production categories were chosen depending on national poultry production specificities (Augère-Granier, 2019). The farms had to reflect the national production profile for their country and farmers were recruited on the basis of their willingness to participate in the study. The choice of the farms by the NF in each country was based on their experience and knowledge of the poultry sectors, implying a degree of subjectivity in farm selection. Consequently, it is necessary to take into consideration this bias in the selection of the farms and the responses collected in our study. Between 21 and 46 farmers were interviewed in each production category, with an expected low number for the free-range meat category (five farmers in two countries). We checked that the overrepresentation of Hungarian (HU) breeder farmers (n = 23) out of 46 total sample had limited impact for the reliability of our results (same BMs least reported as implemented when removing the 23 HU breeders). Given the free choice for the farming system, 37% of the farmers interviewed were independent *vs* 63% under contract with a company (independent farms were distributed in all the seven surveyed production categories and in all the participating countries, except Italy). In order to account for the wide diversity of poultry production categories, the types of farms selected varied, without being representative of European poultry production as a whole, as this was not the objective of the study. However, regarding the diversity of the European poultry sector, this study highlights field-level opinions of a large number of farmers (n = 192) with regard to the implementation of biosecurity on their farms.

Biosecurity implementation is commonly assessed using questionnaires administered by interview to farmers. This assessment can be either quantitative with scoring (Van Steenwinkel et al., 2011; Gelaude et al., 2014; Delpont et al., 2021b) or qualitative (East, 2007). The choice was made to design a qualitative questionnaire considering the full diversity of European poultry production together. As far as possible, the questionnaires were used by only one trained person in each country to limit potential data collection bias. Evaluating the implementation of biosecurity on farms is also complex and challenging, because of the gap between statements made and what is actually applied (Nespeca et al., 1997). To limit this gap, video surveillance in the anterooms or on-farm observations (Racicot et al., 2011; Delpont et al., 2021b) can be used. Being an interview survey, our study is limited to a description of biosecurity implementation as declared by farmers, without an assessment of compliance or actual application of biosecurity measures on the farms. For example, hand washing was reported here as implemented by

most of the farmers, while actual application of this measure was found to be one of the most frequent errors observed in videos on Canadian farms (Racicot et al., 2011). As our study is based on farmers' declarations, it is necessary to consider this bias in the responses collected. However, to attenuate this, an additional interview study with poultry farm advisers, also conducted in the Netpoulsafe project, will provide a complementary view into the implementation of biosecurity measures on farms. Aside from these limitations, this study provides a broad overview of the implementation of biosecurity measures as declared by farmers and highlights the main difficulties and potential obstacles encountered by farmers throughout Europe.

A good overall level of biosecurity in the EU, has been reported on European broiler farms (Van Limbergen et al., 2018) or on Italian poultry farms (broilers, turkeys and layers) (Tilli et al., 2022).

In our study, most of the biosecurity measures presented to the farmers were also reported as "always implemented" (81%). This high biosecurity level declared by the farmers could be explained by the regulatory status of biosecurity, with the European Animal Health Law (Regulation (EU) 2016/429), the specific legislation on regulated poultry diseases (avian influenza, *Salmonella* and *Campylobacter*), the national legislation emphasizing the enforcement of biosecurity following the avian influenza crisis (like in Italy from 2005 (Ministerial order 26.08.2005), Hungary from 2007 and 2013 (Ministerial order 4.12.2007; Ministerial order 30.08.2013) and France from 2016 (Ministerial order 8.02.2016) and also some specific national certifications (like the Belgian Belplume quality system (https://www.belplume.be/) or the Dutch Integral Chain Control (IKB) (https://www.avined.nl)). However, given the response bias related to the difference between the statements made by farmers and what is actually applied, the biosecurity level declared by farmers does not mean that the measures are effectively implemented on the farms.

Considering each poultry production category, biosecurity is reported as more commonly implemented by breeders (87%) and layers farmers (82% enclosed and 81% free-range). This could be explained by the higher control levels of these productions, due to the longer life cycle and the higher value, especially for breeders. Additionally, breeders and layers are included in a *Salmonella* regulation program for longer than the other production categories (Regulation (EC) No 2160/2003) and currently unregulated for ducks, which may explain the lower frequency in this category (74%). A study assessing the actual application of biosecurity measures on farms showed that farm capacity could be related to better biosecurity compliance, likely due to a higher risk of disease transmission and financial losses (Racicot et al., 2012a). Although our study is limited to the farmers' declaration, the same findings could have been expected. The limited number of farms in each production category and the wide range of farming systems in our study could explain these contrasted findings. Considering the farming system, a lower level of biosecurity was here reported on independent farms than on those under contract with a company (79.5% *vs* 82.5%). Lower biosecurity levels were also reported on hobby poultry sites compared to professional farms in Belgium (Van Steenwinkel et al., 2011), and higher implementation levels were found on commercial poultry farms in France (Delpont et al., 2021a). This could be explained by the integration of the poultry industry, increasing biosecurity levels (with mandatory protocols), and poorer availability of technical support with lower specialization levels of independent farms (Souillard et al., 2019).

Our findings show that several BMs were stated highly compliant irrespective of the surveyed poultry production category. Daily surveillance with traceability of flocks and eggs was mentioned as the most common implemented measure by all producers, and flock vaccination for most of them. Proper daily surveillance of birds is one of the fundamental principles in animals farming, and vaccination is a common tool to reduce the risk of disease, reported also highly implemented in European broiler farms (Van Limbergen et al., 2018). Rodent control was mentioned as highly implemented in all the surveyed categories, similarly to a study on Italian poultry farms (Tilli et al., 2022). Rodents are known to be potential carriers or mechanical vectors of various poultry pathogens, particularly *Salmonella* (Davies and Breslin, 2003). Certain standard hygiene practices are also generally reported well complied by the farmers, especially general farm hygiene, such as disinfection of house premises (Tilli et al., 2022) and manure and dead animal management (Van Limbergen et al., 2018). The protection of feed is reported in the most common measures applied in our study in all production categories, but also cleaning/disinfection of the house, secured manure storage, and the presence of a closed rendering tank in most of them. Litter and carcass disposal through a designated area is needed to avoid contamination on the farms (Collett, 2013). The cleaning/disinfection measure was considered as having been applied if both cleaning and disinfection, which is required in order to reach proper decontamination levels, were mentioned as implemented by the farmers. While only one of the two steps may have actually been implemented on these farms, data on this practice has not been collected here, which could be a limitation to consider with regard to this measure.

However, a number of specific hygiene shortcomings were also identified. According to the farmers, the presence of a closed rendering tank seems to be well implemented, but cleaning/disinfection of the tank after each collection is reported to be poorly practiced by most producers. "Lack of training/advice" was more frequently reported by the farmers to explain this low implementation on the farms, but also "lack of time", and "no known advantages", showing poor knowledge and low awareness of the risks and expected benefits of this measure. An uncleaned rendering tank could be a source of contamination for the farm, particularly with regard to *Clostridium botulinum, via* different routes given the risk of potential vectors such as rodents or flies (Souillard et al., 2014). Removal of carcasses by the rendering truck also represents a high risk for the farms (Van Limbergen et al., 2018), requiring specific biosecurity measures to prevent contamination during the truck's movements (protection of containers and isolation from poultry houses). "Cleaning/disinfection of the feed silo and bacterial control of the house after disinfection were also less commonly reported. Cleaning/disinfection of the silo is reported to be difficult, with a fear of moisture retention and mold, probably explaining the most frequent reason "no known advantages" mentioned by the farmers. The cost of the bacterial analysis was commonly mentioned as an obstacle that could, however, be a warning signal to routinely assess the proper cleaning/disinfection of the houses. In a few meat production categories, some other hygiene issues were less commonly declared as implemented (sanitary downtime, disinfection of house and water pipelines, or water analysis), more frequently in the enclosed ducks (not submitted to *Salmonella* regulation) and free-range meat poultry production. Despite the very limited number of free-range meat poultry farmers ($n = 5$), these deficiencies could be due to outdoor access, implying less awareness to comply with biosecurity.

According to the farmers' statements, other biosecurity failures were highlighted for all the surveyed poultry productions. Poor vehicle disinfection prior to entering farms was also reported in Belgium (Van Steenwinkel et al., 2011) and in European broiler farms during depopulation (Van Limbergen et al., 2018). The vehicle flow on farms is a risk for spreading diseases, particularly avian influenza (Duvauchelle et al., 2013; Guinat et al., 2020) (Delpont et al., 2021b). The main reason mentioned by the respondents for not implementing vehicle disinfection was more frequently the "lack of time". This could be explained by the practical difficulties in implementing certain measures, *e.g.*, vehicle disinfection without knowing the arrival time of the trucks. The "personnel/visitor" practices (such as "personnel clothes and hand washing" in meat poultry, "clothes/shoes for egg collectors" in layers and breeders and "showering for farm personnel/visitors") were also reported as less commonly implemented. Compared to some previous studies (Delpont et al., 2018; Van Limbergen et al., 2018), hand washing was reported here as more frequently applied probably due to the Covid pandemic period (people became used to washing/disinfecting their hands). The

use of showers, already reported as being poorly applied by 38.2% of European broilers farmers (Van Limbergen et al., 2018), was also declared here to be "not adapted and not useful" for most of the respondents, except breeders. The BMs to be applied upon entrance to the farms are often reported as being poorly applied in many studies, such as anteroom management on duck farms in France(Delpont et al., 2018), entrance hygiene barriers in European broilers (Van Limbergen et al., 2018), and cleanliness of the hygiene lock in Italian broilers (Tilli et al., 2022). Many biosecurity errors were noted during entry to or exit from poultry houses (Racicot et al., 2011), with 61% of them related to area delimitation, 13.6% to boots, 11.4% to hand washing, and 6.8% to clothes. Compliance with these biosecurity practices is one of the most crucial factors to prevent the introduction of pathogens (Hald et al., 2000; Snow et al., 2010; Ssematimba et al., 2013). There is a higher risk when people are in contact with other poultry during interventions (feed distribution or catching crew for slaughterhouses) and for the egg collection (Thomas et al., 2005). The main obstacle mentioned to compliance with "personnel entry" hygiene practices was "lack of time", pointing out that it was often not a routine practice, could be overlooked, and also considering difficulties in verifying external operators, such as during egg collection.

The movement of people entering a poultry house is known to be a risk of contamination, but also proximity with other animals, like multi-ages sites (Snow et al., 2010), other animal production (Silva et al., 2014), and the presence of wild birds (Wade et al., 2023). As shown in our study, domestic animal management (dog or cats on the farms or backyard poultry) has been reported as poorly implemented (Delpont et al., 2021b). According to the farmers' point of view, the main reason for not being careful with pets on farms was that they "do not know the advantages", which could be a habit and often considering them as companions, guard animals or pest control. The "all in /all out" practice, often mentioned as "not adapted to the farm", was particularly reported as less commonly applied on layer farms (enclosed and free-range), given the need to continuously produce eggs. Similarly, challenges around protecting against wild birds have already been emphasized (Delpont et al., 2021b), and shown in our study with the net mentioned as "not adapted to the farm" by most of the respondents. Given the current development of free-range poultry farming in Europe (Augère-Granier, 2019), new biosecurity requirements with appropriate and tailored biosecurity measures are to be considered in this sector.

To help improve compliance, it is crucial to identify the factors and obstacles associated with the application of BMs on farms. The two components "farming experience" and "education" have already been found to be significantly related to compliance, which was lower in farmers with fewer than five years' experience (Racicot et al., 2012b). Our findings show that farmers 35–55 years of age reported better biosecurity levels which could be related to more farming experience and awareness of biosecurity issues among middle-aged farmers. In the category of farmers $>$ 55 years of age, lower biosecurity levels were declared for the entry of personnel on to the site than when visitors gained entry, potentially implying that they took fewer precautions themselves. Reasons for non-implementation mentioned by farmers often related to misunderstanding of the expected benefits (no known advantages 13%, not useful 12%, and not efficient 35%), especially for pets on farms or feed silo disinfection, and also lack of training (not enough training 5%, and advice 7%) about the need to disinfect the rendering tank after each collection or hand washing before entering the house. Knowledge of biosecurity is a key factor for better compliance on farms (Laanen et al., 2014; Cui and Liu, 2016; Delpont et al., 2021b), reported to be relatively low in a previous study (Laanen et al., 2014). The perceived expected benefit of biosecurity measures is a major determinant, including cost benefits, productivity improvement, and saving time (Laanen et al., 2014; Delpont et al., 2021b). Proving the effectiveness of these practices is also a key factor in the application of biosecurity measures (Gunn et al., 2008; Brennan et al., 2016). Cattle farmers reported that such measures could improve the health of cattle, but that diseases remained inevitable (Richens et al., 2018). The cost of the measures (for example bacterial control) or the lack of time (especially for personnel and vehicle entry) have also often been mentioned as obstacles for performing biosecurity (Siekkinen et al., 2012; Laanen et al., 2014; Millman et al., 2017).

5. Conclusion

Given the huge diversity of poultry farming practices and systems in Europe, this large interview-based qualitative study allowed us to provide an overview of the implementation of biosecurity measures as reported by farmers and to understand the obstacles that they encounter. The study highlighted that farmers reported good biosecurity levels, while showing some deficiencies, including personnel and vehicle entry to farms, the presence of other animals, and certain critical hygiene points. Room for improvement has been demonstrated for certain biosecurity practices, requiring supporting measures and appropriate supervision of the farmers to improve compliance and the motivation to apply biosecurity on their farms. A further Netpoulsafe study targeting poultry farm advisers will provide another point of view on the implementation of biosecurity measures on poultry farms in Europe.

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CRediT authorship contribution statement

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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. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2024.106119.

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