Scoring biosecurity in European conventional broiler production

T. Van Limbergen,∗,1 J. Dewulf,∗ M. Klinkenberg,∗ R. Ducatelle,† P. Gelaude,† J. Méndez,§ K. Heinola,|| S. Papasolomontos,||| P. Szelesczuk,¶ and D. Maes, on behalf of the PROHEALTH consortium∗

∗Department of Reproduction, Obstetrics and Herd Health, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium; †Department of Pathology, Bacteriology and Poultry Diseases, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium; ‡Animal Health Care Flanders, Industrielaan 29, 8820 Torhout; ||COREN, Santa Cruz de Arrabaldo, s/n, 32990 Ourense, Spain; |||Vitatrace Nutrition Ltd., Propylaion 18, Strovolos Industrial Estate, 2033 Nicosia, Cyprus; and ¶Department of Pathology and Veterinary Diagnostics, Division of Avian Diseases, Warsaw University of Life Sciences (SGGW), Nowoursynowska 166, 02–787 Warszawa, Poland

ABSTRACT

Good biosecurity procedures are crucial for healthy animal production. The aim of this study was to quantify the level of biosecurity on conventional broiler farms in Europe, following a standardized procedure, thereby trying to identify factors that are amenable to improvement. The current study used a risk-based weighted scoring system (biocheck.ugent®) to assess the level of biosecurity on 399 conventional broiler farms in 5 EU member states. The scoring system consisted of 2 main categories, namely external and internal biosecurity, which had 8 and 3 subcategories, respectively. Biosecurity was quantified by converting the answers to 97 questions into a score from 0 to 100. The minimum score, “0,” represents total absence of any biosecurity measure on the broiler farm, whereas the maximum score, “100,” means full application of all investigated biosecurity measures. A possible correlation between biosecurity and farm characteristics was investigated by multivariate linear regression analysis. The participating broiler farms scored better for internal biosecurity (mean score of 76.6) than for external biosecurity (mean 68.4). There was variation between the mean biosecurity scores for the different member states, ranging from 59.8 to 78.0 for external biosecurity and from 63.0 to 85.6 for internal biosecurity. Within the category of external biosecurity, the subcategory related to “infrastructure and vectors” had the highest mean score (82.4), while the subcategory with the lowest score related to biosecurity procedures for “visitors and staff” (mean 51.5). Within the category of internal biosecurity, the subcategory “disease management” had the highest mean score (65.8). In the multivariate regression model a significant negative correlation was found between internal biosecurity and the number of employees and farm size. These findings indicate that there is a lot of variation for external and internal biosecurity on the participating broiler farms, suggesting that improvements are possible. Since the subcategory “visitors and staff” scored the lowest, better education of broiler farmers and their staff may help to improve overall biosecurity on broiler farms in Europe.

Key words: biosecurity, disease prevention, European broiler production, risk-based scoring tool

INTRODUCTION

Good biosecurity practices in broiler production are important to reduce the risk of introduction of pathogens causing disease in broilers or pathogens of zoonotic importance (Hald et al., 2000; Gibbens et al., 2001; Graham et al., 2008; Bojesen et al., 2010; Newell et al., 2011). Lower levels of biosecurity indeed lead to a higher prevalence of disease in the case of haemolytic Gallibacterium spp. and a higher risk of flocks getting infected with thermophilic Campylobacter spp. or Salmonella spp. (Gibbens et al., 2001; Liljebljek et al., 2005; Bojesen et al., 2010; Osimani et al., 2017). Biosecurity is also considered important for the control of avian influenza (AI) (Graham et al., 2008; Conan et al., 2012). Therefore, enhanced biosecurity on poultry farms and a restriction of live-bird movements are important control measures that are part of most national AI eradication programs (Conan et al., 2012). Research on biosecurity in broilers is often based on qualitative questionnaires that are specifically designed in the context of a specific disease, without quantifying...
general biosecurity on broiler farms (Nespeca et al., 1997; Gibbens et al., 2001; Tablante et al., 2002; East, 2007; Bojesen et al., 2010; Borck HØg et al., 2011).

In order, to be able to objectively compare the level of biosecurity among farms or within a farm over time in a standardized way, however it is necessary to quantify the level of biosecurity, preferably based on a scientifically substantiated scoring system. For this purpose, the risk-based biosecurity scoring system biocheck.ugent® was developed (Laanen et al., 2010) and successfully used in multiple studies (Laanen et al., 2013; Gelaude et al., 2014; Backhans et al., 2015; Postma et al., 2016).

The aim of the present study was to quantify the level of biosecurity on conventional broiler farms in different European countries, following a standardized procedure, thereby identifying key aspects that would require improvements.

**MATERIALS AND METHODS**

**Farm Selection**

This study was performed in 5 broiler-producing EU member states: Belgium, Finland, Greece, Poland, and Spain. Per country, approx. 50 conventional broiler farms were included. Broiler farms that were producing in free-range or bio-label conditions were excluded. A total of 399 broiler farms participated in this study. By request of the participating poultry companies and as agreed by the PROHEALTH consortium, country codes were used throughout the analysis and to present the results.

**Collection of Farm Data**

All data were collected between February and August 2016. Data were collected during farm visits in Belgium, Greece, and Spain. In Finland and Poland, data were collected through conventional mail and telephone interviews. To ensure inter-farm comparability and to reduce bias by interviewer as much as possible, all interviews were taken by one person per member state. A protocol for the interviews was developed by Ghent University based on discussion and consensus with the different project partners. The specific interviewers per country were instructed about the protocol of the interview during one of the PROHEALTH consortium workshops prior to the start of the farm visits. Interviewers were trained to use a similar approach in performing the farm visit and capturing the necessary information. The biocheck.ugent® questionnaire was pretested and validated when it was developed (Gelaude et al., 2014) and was pretested by the project partners before using it for this study.

Besides the biosecurity data, also some key farm characteristics were collected: presence of other farm animals on the same site, size of the farm (expressed in number of broiler places), yr of experience in keeping broilers, and the number of employees (expressed as full time equivalents (FTE)).

**Quantification of Biosecurity**

Broiler farm biosecurity was quantified by using a risk-based scoring tool. This tool was adapted from Gelaude et al. (2014) and contained 2 main categories, i.e., external and internal biosecurity. Biosecurity was quantified by converting the answers to 97 questions, mainly dichotomous and trichotomous, into a score from 0 to 100. The minimum score, “0,” represents absolute lack of biosecurity on the broiler farm, whereas the maximum score, “100,” means full application of all investigated biosecurity measures. External biosecurity consists of 8 subcategories: 1) purchase of one-day-old chicks, 2) depopulation of broilers, 3) feed and water supply, 4) removal of manure and dead animals, 5) entrance of visitors and staff, 6) supply of materials, 7) infrastructure and biological vectors, and 8) location of the farm. Internal biosecurity consists of 3 subcategories: 1) disease management, 2) cleaning and disinfection, and 3) materials and measures between houses. After completion of the risk-based tool, a score becomes available for external, internal, and overall biosecurity on the broiler farm. A part of the questionnaire is presented in Table 4.

The risk-based tool was described in more detail by Gelaude et al. (2014) and can be consulted for free online: http://www.biocheck.ugent.be/v4/about/poultry/.

**Data and Statistical Analysis**

Differences among member states for overall, external, and internal biosecurity scores, the 11 subcategories, and the farm characteristics were analyzed using analysis of variance (ANOVA) with Scheffé’s method for post hoc comparison. Correlation between external and internal biosecurity scores was assessed by using the 2-way Pearson correlation coefficient. Correlations greater than |0.6| were considered as strong correlations, whereas correlations between |0.3| and |0.6| were considered as weak correlations (Dohoo et al., 2009).

For the analysis of correlations between the biosecurity scores (dependent variable) and farm characteristics (independent variables; i.e., farm size, yr of experience, number of employees (FTE), and number of broilers per FTE, first univariable regression analysis was performed. Variables with P-values of < 0.20 and that were not strongly correlated were retained for further analysis in a multivariable model. The multivariable model was constructed by using a stepwise backward selection procedure, also including testing of 2-way interactions of significant main effects. As we were interested in correlations beyond the member state effect, member state was always included as a fixed factor in
the model to account for these effects. Correlations were considered to be significant if \( P < 0.05 \). Normal probability tests and plots were examined to check whether the assumptions of normality and homoscedasticity of the residuals were fulfilled. A log_{10} transformation for the number of broilers and the numbers of broilers per FTE was required for these assumptions.

All statistical analyses were performed using IBM SPSS version 23®, Armonk, New York.

**RESULTS**

**Farm Characteristics**

A total of 399 broiler farms was included in this study. An overview of the number of farms per member state is presented in Table 1.

Eighty-six percent (n = 349) of the broiler farms that participated in this study had no other farm animals on the same site (Table 1). The remaining 14% of broiler farms that also had other farm animals produced pork (n = 20) or beef (n = 15), or had dairy cattle (n = 9) or other types of poultry (n = 6).

The farm characteristics of the participating broiler farms are shown in Table 2. The overall mean (standard deviation) farm size was 51,761 (46,895) broilers.

The animal caretakers had a mean level of experience in broiler production of 19.40 (11.43) years. The mean broiler farm employed 1.53 (0.82) FTE. The mean number of broilers per FTE was 31,879 (23,406).

**Biosecurity Scores**

An overview of the scores for overall, external, and internal biosecurity and their subcategories is presented in Table 3. Table 3 also contains the results of the ANOVA analysis that was performed between the 5 member states.

The mean overall score for all countries was 70.9. Overall biosecurity scores ranged from 60.8 to 77.7. The differences were insignificant among member states A, B, and D. The mean external biosecurity score (68.4) was lower than internal biosecurity (76.6), and scores ranged from 53.5 to 95.5 among countries. The boxplots per member state for overall, external, and internal biosecurity also show the large variation among and within member states (Figure 1). External and internal biosecurity were positively correlated (\( R = 0.48; P < 0.01 \)) with each other (Figure 2).

**Link Between Biosecurity Scores and Farm Characteristics**

The univariable analysis, corrected for member state effect, resulted in retaining 3 farm characteristics for external and internal biosecurity, i.e., farm size, experience, and FTE. The independent variable “number of broilers per FTE” did not significantly affect internal biosecurity (\( P = 0.354 \)) and was strongly correlated with farm size (\( r = 0.82 \)). Therefore “broilers per FTE” was not used for the multivariate analysis.

In the final multivariable model, farm size was negatively associated (\( P < 0.01 \)) with external biosecurity, whereas number of FTE (\( P < 0.01 \)) was again positively associated, whereas number of FTE (\( P < 0.01 \))
working at the farm was here negatively associated with the internal biosecurity. The equation for the regression line was: Internal biosecurity = 112.90 – 6.80 (log10 farm-size) – 2.15 (FTE). Eleven percent of the variability in internal biosecurity was explained by farm size and FTE, which were both negatively associated with internal biosecurity.

**DISCUSSION**

This study assessed the biosecurity status on conventional broiler farms in 5 EU member states. It was agreed among the participating investigators within each country that all participating farms in a country needed to be as representative for the broiler industry of that specific country as possible, preferably by using a randomized sample of the local broiler industry. As it was impossible to establish a full randomization in the selection of the farms, a selection bias is likely present to some extent. The mode of questionnaire administration was identified previously to have a serious effect on data quality (Bowling, 2005). For this reason, the current study encouraged data collection by farm visits, where a personal contact was possible between the interviewer and the poultry farmer. Nevertheless, the data from 2 out of 5 countries were collected via conventional mail or telephone interviews instead of farm visits. The potential loss of data quality by the different modes of questionnaire administration in these 2 countries could therefore not be excluded. The interviewers

---

**Table 2.** Descriptive information of the participating farms regarding main farm characteristics.

<table>
<thead>
<tr>
<th>Farm characteristic</th>
<th>Member states</th>
<th>Mean</th>
<th>Median</th>
<th>SD$^2$</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of broilers$^1$</td>
<td>A</td>
<td>67,296</td>
<td>67,833</td>
<td>30,013</td>
<td>20,750</td>
<td>180,000</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>30,167</td>
<td>23,500</td>
<td>16,627</td>
<td>7,650</td>
<td>72,726</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>70,654</td>
<td>58,000</td>
<td>51,253</td>
<td>9,000</td>
<td>250,000</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>34,569</td>
<td>24,000</td>
<td>44,816</td>
<td>5,400</td>
<td>300,000</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>56,116</td>
<td>40,000</td>
<td>55,170</td>
<td>11,000</td>
<td>405,000</td>
</tr>
<tr>
<td></td>
<td>Overall$^2$</td>
<td>51,761</td>
<td>31,000</td>
<td>46,894</td>
<td>5,400</td>
<td>405,000</td>
</tr>
<tr>
<td>Years of experience of farmer</td>
<td>A</td>
<td>23.64</td>
<td>24.00</td>
<td>9.01</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>21.97</td>
<td>20.00</td>
<td>9.45</td>
<td>10</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>21.96</td>
<td>23.50</td>
<td>9.46</td>
<td>6</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>17.06</td>
<td>14.00</td>
<td>12.51</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>19.33</td>
<td>20.00</td>
<td>11.00</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Overall$^2$</td>
<td>19.40</td>
<td>18.00</td>
<td>11.43</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Full-time equivalents (FTE)</td>
<td>A</td>
<td>1.16</td>
<td>1.00</td>
<td>0.37</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>1.92</td>
<td>2.00</td>
<td>0.87</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>1.98</td>
<td>2.00</td>
<td>0.96</td>
<td>0.5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>1.36</td>
<td>1.00</td>
<td>0.60</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>1.69</td>
<td>1.00</td>
<td>1.10</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Overall$^2$</td>
<td>1.53</td>
<td>1.00</td>
<td>0.82</td>
<td>0.5</td>
<td>6</td>
</tr>
<tr>
<td>Number of broilers per FTE</td>
<td>A</td>
<td>59,266</td>
<td>55,250</td>
<td>24,107</td>
<td>20,750</td>
<td>116,000</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>16,497</td>
<td>16,626</td>
<td>7,955</td>
<td>4,896</td>
<td>38,760</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>38,573</td>
<td>34,250</td>
<td>25,522</td>
<td>7,500</td>
<td>137,000</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>24,992</td>
<td>21,875</td>
<td>17,343</td>
<td>2,700</td>
<td>100,000</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>34,025</td>
<td>27,750</td>
<td>23,726</td>
<td>8,750</td>
<td>135,000</td>
</tr>
<tr>
<td></td>
<td>Overall$^2$</td>
<td>31,879</td>
<td>24,000</td>
<td>23,406</td>
<td>2,700</td>
<td>137,000</td>
</tr>
</tbody>
</table>

$^1$Broiler housing capacity of the farm.
$^2$Standard deviation.
$^3$Overall: Calculated on the complete dataset of farms that participated in this study, i.e., 399 broiler farms.

**Table 3.** Overall, external, and internal biosecurity scores [mean values (standard deviation)] on broiler farms in 5 countries, including their specific subcategories.

<table>
<thead>
<tr>
<th>Category/Member state</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>All$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall biosecurity</td>
<td>75.4$^a$ (3.5)</td>
<td>77.7$^a$ (5.1)</td>
<td>60.8$^b$ (5.9)</td>
<td>73.7$^a$ (4.4)</td>
<td>66.9$^c$ (13.1)</td>
<td>70.9</td>
</tr>
<tr>
<td>External biosecurity</td>
<td>71.1$^a$ (4.5)</td>
<td>78.0$^b$ (4.9)</td>
<td>59.8$^c$ (7.1)</td>
<td>69.7$^a$ (6.0)</td>
<td>63.6$^c$ (15.7)</td>
<td>68.4</td>
</tr>
<tr>
<td>Purchase day-old chicks</td>
<td>66.5$^a$ (15.5)</td>
<td>58.3$^b$ (3.5)</td>
<td>55.3$^c$ (11.9)</td>
<td>75.5$^d$ (13.9)</td>
<td>62.5$^e$ (21.4)</td>
<td>63.6</td>
</tr>
<tr>
<td>Depopulation</td>
<td>58.7$^a$ (9.2)</td>
<td>68.5$^b$ (0.0)</td>
<td>62.9$^b$ (13.9)</td>
<td>49.9$^a$ (9.1)</td>
<td>57.4$^a$ (16.0)</td>
<td>59.5</td>
</tr>
<tr>
<td>Feed and water supply</td>
<td>56.0$^a$ (14.0)</td>
<td>84.2$^b$ (18.3)</td>
<td>61.9$^b$ (19.3)</td>
<td>57.1$^a$ (12.3)</td>
<td>59.9$^a$ (24.2)</td>
<td>63.8</td>
</tr>
<tr>
<td>Manure and dead animals</td>
<td>97.4$^a$ (6.4)</td>
<td>89.9$^b$ (13.6)</td>
<td>52.1$^a$ (29.3)</td>
<td>88.9$^a$ (10.5)</td>
<td>69.3$^b$ (22.6)</td>
<td>79.5</td>
</tr>
<tr>
<td>Visitors and staff</td>
<td>48.9$^a$ (4.9)</td>
<td>65.7$^b$ (1.9)</td>
<td>49.1$^b$ (8.7)</td>
<td>47.8$^b$ (11.1)</td>
<td>46.4$^b$ (21.0)</td>
<td>51.6</td>
</tr>
<tr>
<td>Supply of materials</td>
<td>65.0$^a$ (30.2)</td>
<td>100.0$^b$ (0.0)</td>
<td>47.4$^b$ (22.9)</td>
<td>58.1$^b$ (14.3)</td>
<td>68.0$^a$ (34.2)</td>
<td>67.7</td>
</tr>
<tr>
<td>Infrastructure and vectors</td>
<td>86.3$^a$ (8.5)</td>
<td>88.2$^b$ (5.7)</td>
<td>73.2$^b$ (8.1)</td>
<td>88.2$^b$ (5.3)</td>
<td>76.1$^b$ (19.2)</td>
<td>82.4</td>
</tr>
<tr>
<td>Location of the farm</td>
<td>66.6$^b$ (23.3)</td>
<td>69.5$^c$ (11.1)</td>
<td>53.9$^b$ (23.4)</td>
<td>66.6$^a$ (20.6)</td>
<td>57.5$^c$ (24.8)</td>
<td>62.8</td>
</tr>
<tr>
<td>Internal biosecurity</td>
<td>85.6$^a$ (3.9)</td>
<td>76.8$^b$ (6.0)</td>
<td>63.0$^a$ (6.3)</td>
<td>83.2$^a$ (4.8)</td>
<td>74.5$^b$ (11.1)</td>
<td>76.6</td>
</tr>
<tr>
<td>Disease management</td>
<td>94.6$^a$ (3.0)</td>
<td>95.5$^b$ (6.2)</td>
<td>53.5$^c$ (7.4)</td>
<td>86.1$^a$ (5.1)</td>
<td>89.0$^a$ (10.9)</td>
<td>83.8</td>
</tr>
<tr>
<td>Cleaning and disinfection</td>
<td>78.0$^a$ (4.6)</td>
<td>78.9$^b$ (13.5)</td>
<td>72.6$^d$ (7.5)</td>
<td>77.3$^e$ (4.1)</td>
<td>69.1$^a$ (13.6)</td>
<td>75.2</td>
</tr>
<tr>
<td>Inter-house management</td>
<td>81.2$^a$ (11.6)</td>
<td>39.2$^b$ (13.6)</td>
<td>65.2$^a$ (19.7)</td>
<td>87.0$^b$ (17.6)</td>
<td>56.7$^c$ (27.4)</td>
<td>65.9</td>
</tr>
</tbody>
</table>

$^a$–$^d$Similar superscripts indicate statistical equality, while different letters indicate statistical significant differences between countries.
$^1$Mean biosecurity scores for the 5 countries.
of both countries have cross checked the replies to the questionnaires, when possible, with data that were already recorded on these farms for other purposes to limit the potential loss of data quality.

The possible interviewer bias was limited as much as possible by limiting the number of people responsible for the collection of data and also by training the interviewers to follow a specific predesigned procedure during the farm visit. The relatively high number of farms that was included in this study, almost 400 broiler farms, also enhances the representativeness. The major disease concerns and control measures in relation to those diseases listed by the World Organization for Animal Health (OIE) were similar in the participating member states with the exception of Finland, which does not apply a prophylactic vaccination policy in the control of Newcastle disease and appears to be free of clinical signs of infectious bronchitis and infectious bursal disease (Finnish Food Safety Authority Evira, 2016). The farm characteristics of the 5 participating member states were in accordance with previous results obtained from the same countries (Borck HØg et al., 2011).

The overall biosecurity score was 70.9, but a wide range in scores was found among the participating member states. Member state means had a range of almost 17 points (i.e., between 60.8 and 77.7). The main
Figure 2. Correlation between external and internal biosecurity on broiler farms. The correlation was represented by the fitted line over all combined data. The different countries are represented by different markers. R represents the coefficient of correlation between internal and external biosecurity.

reasons for this wide range are the high score for external biosecurity in member state B and the high scores for internal biosecurity in member states A and D, which were significantly higher compared to the other member states and led to the upper side of the range that was found in overall biosecurity among member states. The bottom side of the range is mainly caused by the scores obtained by member state C, which had the lowest score for overall biosecurity. However, the external biosecurity score for member state C was not significantly different from the score obtained by member state E. The main reason for the low overall biosecurity score in member state C was the low score in internal biosecurity score, which was 11.5 points lower than the second lowest score (member state E) and 22.6 points lower than the member state with the highest score for internal biosecurity (A).

The scores for subcategories varied by country. Within the category of external biosecurity, high scores were obtained in the subcategories “Manure and dead animals” and “Infrastructure and vectors.” Dead animals and used litter (manure) have been identified as potential sources for various pathogens. Dead animals potentially died from infectious diseases, but also the incorrect on-farm storage and off-farm removal of these cadavers impose threats, as the cadavers become a source of infection (Meroz and Samberg, 1995; McQuiston et al., 2005). Good biosecurity practices implement the removal of cadavers from the broiler house as soon as possible (Meroz and Samberg, 1995) and a correct storage and disposal by a rendering company (Evans and Sayers, 2000). Used litter has been identified as being highly contaminated with multiple types of pathogens; therefore, on-farm storage poses a risk for biosecurity and health of broilers (Lister, 2008). Member state C scored significantly lowest for subcategory “Manure and dead animals,” which contributed to the low score for external biosecurity. The low score for member state C could partially be caused by the fact that the risk-based tool mentions only disposal of carcasses via a rendering plant. On-farm disposal of broiler carcasses, e.g., by incineration or by composting, also is used in some countries (Blake and Donald, 1992) and was mentioned by Lister (2008) as the method of choice in order to avoid spread of pathogens by carcass storage or disposal. Research that was performed outside Europe showed that a high number of broiler farms used on-farm disposal of carcasses (Vieira et al., 2009; Dorea et al., 2010; Tabidi et al., 2014). The importance of pathogen introduction by rodents, wild birds, insects, pets, and other farm animals was demonstrated by numerous authors for a large
variety of pathogens (Refregier-Petton et al., 2001; Boes et al., 2005; Liljebeke et al., 2005; Amass and Baysinger, 2006; Graham et al., 2008; Tablante, 2008). These topics were addressed in the subcategory “Infrastructure and vectors.” Broiler farmers tend to be aware of the importance of good policy regarding their infrastructure and potential vectors, as this subcategory scored highest within all subcategories in the category of external biosecurity. The need for biosecurity measures, and therefore risk scores per subcategory, may vary by country because the source of disease risks may vary by farm and country.

The lowest scores within the category of external biosecurity were obtained in the subcategories “Depopulation” and “Visitors and staff.” For subcategory “Depopulation,” scores among member states ranged between 49.9 and 68.5. The best scores were obtained by member states B and C, while the lowest score was obtained in member state D. Depopulation of broilers is a risk for introducing pathogens, as this involves animal-transport vehicles and often also a catching team to enter the farm premises (Fritzemeier et al., 2000; Hege et al., 2002). Therefore, depopulation must be done in as few steps as possible, farm-specific clothing and footwear need to be provided to the catching team, and it is recommended that at least the wheels of the transport vehicle are disinfected before entering the poultry farm (Lister, 2008; McDowell et al., 2008; Vieira et al., 2009). Subcategory “Entrance of visitors and staff” obtained the lowest score compared to all other subcategories (including the subcategories present in internal biosecurity). Member state B obtained the best score, while there was no significant difference among the other member states. Member states A, C, D, and E scored below 50 points. Nevertheless, this is one of the most critical factors to protect a farm from pathogens entering. Movement of people has been associated with the spread of highly pathogenic AI (Thomas et al., 2009). Both the number of visitors and the number of people involved in the daily care should therefore be limited (Kapperud et al., 1993; Refregier-Petton et al., 2001; Lister, 2008). A similar finding also was reported by Van Steenwinkel et al. in 2011. Racicot et al. (2011) stated that a lot of biosecurity errors happen when people enter or leave poultry farms. Nevertheless, this is probably one of the easiest and least expensive ways to improve biosecurity on a broiler farm. The costs of biosecurity measures related to people entering the livestock farm are fairly small (Siekkinen et al., 2012; Niemi et al., 2016).

Racicot et al (2011) investigated the specific biosecurity errors that were made by visitors, using hidden cameras. The most frequent errors (61.4%) were related to violation of the clean area vs. contaminated area. This indicates that the presence of an infrastructure that makes good biosecurity practices possible is no guarantee that good biosecurity procedures will be followed during daily routines. The latter also was shown by Dorea et al. (2010) in Georgia in the United States. In our study, only 30% of the participating farms had a farm hygiene lock, and 32% of these farms indicated that there was no strict separation between the clean and dirty areas of the farm hygiene lock. Broiler farms with multiple broiler houses on the same site more often had a farm hygiene lock compared to single-house farms [37.3 vs. 17.8%, respectively (results not shown)]. It was shown that missing a hygiene barrier poses a threat for the entrance of pathogens (Hald et al., 2000; East et al., 2006). In contrast to the absence of a farm hygiene lock in almost 70% of the participating farms, 346 out of 399 farms (86.7%) indicated that they had a house hygiene lock. Gibbens et al. (2001) demonstrated that a standard hygiene protocol followed by all staff who entered a populated broiler farm could reduce the risk of a flock getting infected with thermophilic Campylobacter spp. by 50%. This hygiene protocol included a strict procedure with boot dips before entering the farm and house-specific clothing. The latter also demonstrates the importance of a specific farm and house hygiene lock in preventing (zoonotic) pathogens from entering a broiler house. In our study, a total of 41 farms (10%) indicated that they had no farm or house hygiene lock, meaning that there was no clear separation between the clean area and the contaminated area. Also, in the control of AI, a stricter external biosecurity, including procedures for visitors and staff in order to reduce the risk of the pathogens spreading to uninfected farms, is advised (McQuiston et al., 2005; Graham et al., 2008; Conan et al., 2012).

Within the category of internal biosecurity, the highest score was obtained in the subcategory “Disease management,” while the lowest score was obtained in “Inter-house management.” Member states A and B scored significantly higher than the other member states; member state C, on the other hand, scored almost 30 points lower than the second lowest scoring member state, D. Within the subcategory of “Disease management,” a large number of questions are associated to vaccination protocols, as vaccination in poultry is as an important control measure for many (mainly viral) diseases that are ubiquitously present (Sims, 2007; Cserep, 2008). Good vaccination protocols enable good broiler performance in regions with a high level of endemic diseases, whereas regions with a very low disease pressure may not require the application of certain vaccinations (Dekich, 1998). In such regions, vaccination protocols are essential. However, as part of an eradication program, a member state could decide not to tolerate seropositivity of poultry for a certain disease. In this case, vaccination for this specific disease can be prohibited (Schelling et al., 1999). The risk-based tool used in this study did not take into account this specific reason for potential absence of vaccinations in member states, together with an increased level of biosecurity. The latter might partly explain the low score for member state C in this study. The subcategory that obtained the lowest score in internal biosecurity was “Inter-house management.” Member state A scored highest in this
subcategory, while member state B scored significantly lowest. Inter-house management is important, as one caretaker who is responsible for several poultry houses can spread pathogens among these houses (Kapperud et al., 1993). The latter might be improved by education of farm staff about the principles and positive effects of biosecurity (Laanen et al., 2014; Lewerin et al., 2015).

The same questionnaire was previously used by Gelaude et al. (2014) during a pilot study of 15 broiler farms. Gelaude et al. (2014) found a mean external biosecurity score of 64 and a mean internal biosecurity score of 73, which was slightly lower than the mean results for the 5 member states in the current study. Several explanations are possible for this difference. First, the current study included broiler farms from 5 EU member states, whereas significant differences could be found among member states. Second, Gelaude et al (2014) investigated only 15 broiler farms, whereas the current study included almost 400 broiler farms and thus might provide a better representation of the biosecurity on broiler farms. A third reason could be increased awareness on improving biosecurity, e.g., by recent AI outbreaks (Dorea et al., 2010; Sandberg et al., 2016).

Internal biosecurity scored higher than external biosecurity in most of the countries. This confirms previous results by Gelaude et al. (2014). A possible explanation for this difference could be related to the beneficial effect on performance of good internal biosecurity procedures. Tablante et al. (2002) showed that an increased frequency of sanitizing the drinking lines was associated with higher flock performance. This suggests that a clear benefit from improving internal biosecurity might be an important incentive for broiler farmers to implement a higher standard of hygiene in the broiler house. The same was found in a recent similar study that investigated biosecurity levels in farrow-to-finish pig herds in Europe (Postma et al., 2016). These researchers found a clear benefit in performance and antimicrobial treatment parameters for pig herds that achieved higher levels of internal biosecurity. Siekkinen et al. (2012) calculated the cost paid by broiler producers for biosecurity to approximately 3.55 eurocent per bird. This not only included structural biosecurity but also preventive medication (e.g., coccidiostats), pest control, and operational hygiene.

The current study identified correlations between external and internal biosecurity scores and farm characteristics, included in the questionnaire. The current survey contained a lot of farm size differences; during the statistical analysis, farm size was found to be normally distributed for each member state separately and for all member states together. Data were checked for outliers, and as farm size was one of the factors we were interested in, no farms were excluded based on their size. Member state was added in the model as a fixed factor in order correct for member state effect in the multivariable model. Farm size appeared to be negatively associated with both external and internal biosecurity scores. Dorea et al. (2010) found that farm size or the number of broiler farms owned by a broiler producer did not influence biosecurity scores. Increased farm size was previously shown to be a risk factor for highly pathogenic AI outbreaks in the Netherlands and Italy (Thomas et al., 2005; Busani et al., 2008). A possible explanation for the negative correlations that were found in the current study might be the risk-based design of the biosecurity tool that was used for the calculation of the biosecurity scores. For external biosecurity, the number of feed deliveries, multiple feed suppliers, and obtaining day-old chicks from several different hatcheries were quoted and had a negative impact on the biosecurity score, as a higher number of suppliers or deliveries also increases the risk of pathogens being introduced onto the farm (Thomas et al., 2005; Lister, 2008; Vieira et al., 2009). The negative correlation between farm size and internal biosecurity score might be linked with the presence of a larger number of poultry houses on larger-sized farms. Internal biosecurity is scored by assessing “disease management,” “cleaning and disinfection,” and “material and methods between houses.” A good protocol for inter-house management and house-specific materials is highly important to prevent the spread of pathogens among broiler houses (Kapperud et al., 1993). Besides the above-mentioned correlations, other parameters that were not captured by the questionnaire also might be responsible for a part of the variation that was found, as the statistical model explained only a part of the variation in biosecurity scores.

A weak positive correlation was found between the number of FTE and external biosecurity scores. This finding is not supported by literature, as in literature, external biosecurity is considered to decrease when more FTE are employed at the farm (i.e., a negative correlation between external biosecurity and number of FTE) (McQuiston et al., 2005; Thomas et al., 2005; East, 2007; Kung et al., 2007). A possible explanation could be that a higher number of FTE allows people to spend more time to address some key issues related to external biosecurity, such as the daily cleaning and disinfection of the materials that are used to remove dead animals from the broiler house. In contrast to external biosecurity, a negative weak correlation was found between the number of FTE and internal biosecurity. This finding is supported in literature, as a higher number of staff increases the risk of pathogens being spread among poultry houses (Kapperud et al., 1993; Refrégier-Petton et al., 2001). These results suggest that farms with a higher number of broilers and more staff involved in the daily care of the animals have more difficulties in maintaining a good level of internal biosecurity.

East (2007) performed a survey of 1,753 Australian poultry farms to assess the level of biosecurity. The main findings were that Australian poultry farms in the chicken meat, turkey, and duck sectors had a high level of standard biosecurity practices with only a small proportion of farms needing to further enhance their level...
of biosecurity. However, these conclusions were based on the interpretation of the individual questions without calculating an overall score for the participating farms; additionally, participants could choose not to answer certain questions, which might lead to bias in the completion of questions that could have a positive answer for certain farms and avoiding those questions that could be identified as weak points related to biosecurity on the farm.

In conclusion, the present study indicated that there is a lot of variation for both external and internal biosecurity among the participating broiler farms, suggesting that a lot of improvements can be made. External biosecurity tended to score lower than internal biosecurity. The subcategory that scored the lowest in the participating farms was “Visitors and staff.” Education of broiler farmers and their staff about good biosecurity procedures and their implementation remains very important.

ACKNOWLEDGMENTS

The PROHEALTH consortium would like to thank all participating broiler farmers, integrators, and farm veterinarians for their kind cooperation. The authors would also like to thank the PROHEALTH consortium for its help in facilitating this study.

This project has received funding from the European Union’s Seventh Framework Programme for research, technological development, and demonstration under grant agreement no: 613574.

REFERENCES


