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Identification of Production Chain Risk Factors for Slaughterhouse Condemnation of Broiler Chickens'

S.N. BUZDUGAN[11], Y.M. CHANG[2], B. HUNTINGTON[3], J. RUSHTON[4], J. GUITIAN[1], P. ALARCON[1] AND D.P. BLAKE[5]

[1]Veterinary Epidemiology, Economics and Public Health Group, Royal Veterinary College, Hawkshead Lane, Hatfield, Hertfordshire, AL9 7TA, UK

[2]Research Support Office, Royal Veterinary College, Royal College Street, NW1 0TU, UK

[3]Liverpool Science Park, Innovation Centre 2, 146 Brownlow Hill, Liverpool, L3 5RF

[4]Epidemiology and Population-Health, Liverpool University, Brownlow Hill, Liverpool, L69 7ZX, UK

[5]Pathobiology and Population Sciences, Royal Veterinary College, Hawkshead Lane, Hatfield, Hertfordshire, AL9 7TA, UK

[1] Svetlana Nikolayevna Buzdugan, Royal Veterinary College, Hawkshead Lead, North Mymms, Hertfordshire, AL9 7TA, UK. Email: sbuzdugan1@rvc.ac.uk

Abstract

Slaughterhouse condemnation of broiler chickens results from identification of polymorphic pathological conditions during meat inspection from arrival and on theslaughter line . While conditions that result in condemnation are multifactorial, identification of factors that are common for a number of categories could be valuable for developing strategies to reduce total condemnation. This study aimed to identify those condemnation categories that were most common in batches of broiler chickens and to determine and compare associated risk factors. In the first step, retrospective meat inspection records for 55,918 broiler batches from one large broiler integrator for 2015-2017 were used for association rules analysis. Results identified a network of nine associated condemnation categories: whole carcass condemnation for ascites, abnormal colour, perihepatitis, cellulitis, hard breast, tumours and dead on arrival, and liver only and heart only most often associated with hepatitis and pericarditis, respectively. Whilst the longitudinal study collected data on 109 explanatory variables from broiler parental flocks to slaughterhouse characteristics between January 2015 and December 2017. Condemnation outcome data were obtained from meat inspection records for 539 broiler batches participating in the study. Parental flock-, rearing farm-, shed- and transport-level risk factors were assessed for each outcome using mixed-effects multivariable Poisson regression including shed and farm as random effects. A Poisson regression tree method was used as the first step to identify variables most relevant for analysis and comparison across the outcomes. No single production factor was associated with all nine of the condemnation outcomes investigated in this study, although some were shared across multiple outcomes: age of parental flock at time of lay, flock-level *Campylobacter* spp. frequency, broiler chick weight at seven days of age, weight at slaughter, type of broiler removal (i.e. thinning, final depopulation), catcher team, number of birds per transport crate, slaughterhouse shift number, and type of slaughterhouse line. Broiler chickens removed during final depopulation were at greatest risk of condemnation. Condemnation rates for cellulitis and tumours were found to be higher in broilers inspected by night shift at the slaughterhouse. Discovery of an apparent protective effect of a higher number of broilers per transport crate was unexpected. These findings provide information for the broiler industry on production chain factors that might be amenable to targeted intervention to improve future efforts for control of condemnation.

Keywords:

Risk factors, condemnation categories, broiler production

1. Introduction

In broiler chicken populations the incidence of condemnation during slaughterhouse meat inspection can be used to provide a quantitative measure of some morbidities that may be associated with on-farm, in transit or processing level risk factors. Control strategies and improvements in husbandry to reduce morbidities may focus on individual factors, such as the occurrence of a pathogen, or be combined in a blanket approach to alleviating multiple interlinked morbidities (Dekich, 1998). The latter approach may be particularly amenable for broiler chickens reared within intensive agricultural systems since most are commonly produced in homogeneous units.

Broiler chickens are commonly reared in intensive, integrated systems in the UK that are characterised by a close relationship between farmers/managers and a small number of large integrator companies. Such integrated systems can include provision of day old chicks, feed and veterinary support, with finished stock collected and processed by the same company. Integration permits close control of chicken genetics, husbandry, welfare and prophylaxis, At the end of rearing each broiler flock is collected, either manually or using modular catching devices, and divided into batches to be transported and slaughtered as a unit. Thinning can be practised, removing a proportion of a flock earlier than the majority. Gross abnormalities detected during slaughterhouse processing are classified using a defined list of reasons, producing composite condemnation outcomes for batches of broiler chickens. Detecting batch-level associations between multiple morbidities and identifying their common risk factors could highlight specific health concerns and point towards potential interventions.

Broiler slaughterhouse condemnation has been demonstrated to have a multifactorial nature (St-Hilaire and Sears, 2003; Haslam et al., 2007, 2008; Lupo et al., 2009). Previous studies on slaughterhouse condemnation during meat inspection have focused on (i) the frequency of individual, grouped, or total condemnation categories, and/or (ii) risk factors for individual or total condemnation categories (Haslam et al., 2007, 2008; Lupo et al., 2009; Lupo et al., 2010). Despite the link to broiler health and welfare, research into condemnation outcomes has been scarce (Stärk et al., 2014; Salines et al., 2017). Research on multimorbidity occurrence is a more recent approach to studying condemnation. For example, links between multimorbidity and population health status have been demonstrated with cattle used for meat production through the application of cluster and multiple factor methods (Dupuy et al., 2013).

Recognising that most of the research in broiler chickens has focused on a practical understanding of individual condemnation categories, this study was intended to identify the most prevalent co-morbidities diagnosed during broiler meat inspection and assess the occurrence of shared production chain risk factors.

2. Materials and Methods

2.1. Data collection

The study population consisted of Ross 308 broiler chickens raised using conventional commercial methods by an integrator company located in England (Aviagen ROSS, 2018). The study unit was a broiler batch, defined as a group of broiler chickens reared on the same farm, in the same shed, which was harvested and transported together on the same vehicle, and was slaughtered and inspected as a unit.

The study was carried out using a mix of retrospective and prospective data. Initially, meat inspection records on condemnation reasons were obtained retrospectively for all broiler batches raised and processed by the integrator between January 2015 and December 2017. Subsequently, a longitudinal study design was used to collect production chain information from farms supplying broilers to the integrator's slaughterhouse. All farms were approached quarterly, once in a calendar season of a study year, between April 2017 and March 2018, to collect information pertaining to the farm and a specified broiler flock via a postal questionnaire. In each study round, all farms working with the company, a total of 83 during the study period, were asked to complete a questionnaire concerning one broiler shed. The shed to be sampled was selected for each data collection round using the available sampling frame, which constituted a list of operational broiler sheds for each farm. Every farm, regardless of its size, was asked to provide information about one broiler shed and the broiler flock being reared in it. However, unweighted sampling was chosen to simplify data collection procedures and to maximise farm response rate. On farms with four sheds, one shed was systematically selected per data collection round. On farms with more than four sheds, sheds were sampled at random. On farms with three or fewer sheds, sheds were selected using a combination of systematic and random selection. Initially, one shed was selected per season, rotating to ensure that all sheds were sampled. In subsequent study rounds, or once all the sheds were sampled, a shed was selected for the study at random. Consequentially, the probability of a flock being sampled was not the same for all flocks, with flocks from smaller farms having a higher probability. Random selection was conducted using the random number generator function in Microsoft Excel (2016).

Farm-level information regarding rearing, management and transport practices, broiler characteristics and health history, was collected in a standardised questionnaire and from the integrator's electronic records, linking them to their specific batch-level slaughterhouse outcomes (Table 1). A total of 109 explanatory variables were included in the analysis.

For the longitudinal study, a sample of 389 broiler batches with a minimum size of 1,000 chickens was calculated to be sufficient to detect a variation of 20% from the baseline condemnation rate of 1% and, assuming a 1:1 ratio on the presence/absence of a risk factor, at 5% significance for Poisson regression with 85% power. Sample size accounted for the design effect using the intracluster correlation coefficient (ICC of 0.23), estimated in mixed-effect Poisson regression analysis conducted in a pilot study (author's unpublished data) (Signorini, 1991; Gelman and Hill, 2006).

Definition of outcome variables

For each broiler batch, outcomes were expressed as the rate of condemnation cases per 1,000 processed broilers for every condemnation category. Twenty-three health and welfare-related condemnation categories that were recorded as outcomes during the meat inspection process by the integrator slaughterhouse were used in the first analytical stage of the study (Table 2). Batch-level rates of condemnation cases were categorised based on median values for each of the 23 categories and coded as follows: 1 for values above the median; 0.5 for values equal to the median or below; and batches with no occurrence recorded for any given condition were coded 0.

At the conclusion of the initial analysis, condemnation categories for ascites, abnormal colour, perihepatitis, cellulitis, hard breast, tumours and dead on arrival, as well as partial condemnation of liver only (perihepatitis) and heart only (pericarditis), were prioritised as outcomes of interest. A composite outcome variable was included, representing the total rate of condemnation due to all nine of these condemnation categories combined. Condemnation records were linked to the corresponding flock and farm-level data obtained from company records and the postal survey for statistical analysis.

2.2. Statistical analysis

First, association rules analysis was applied to the retrospective data to identify the most prevalent associations between condemnation categories. Subsequently, production chain factors that were similarly linked to these associated condemnation categories were identified. Poisson regression tree analysis was used to assess associations of a high number of explanatory variables with each of the nine chosen and one combined condemnation outcomes. Then, associations between explanatory variables and the outcomes were explored in multivariable mixed-effect Poisson regression models.

Association rules analysis

Analysis was conducted using retrospective condemnation records to identify the most prevalent associations with confidence ≥80% (i.e. conditional probability between condemnation reasons) and support ≥10% (i.e. frequency of a rule in a dataset, where the 'rule' was a group of associated condemnation reasons that followed an "*if this then that*" expression). The generated rules were pruned using Bayardo improvement, where a rule was removed when a more general rule with the same consequent and the same or higher confidence was available (Bayardo et al., 1999). Association rules analysis was conducted in two successive steps. First, the whole dataset of broiler batch-level records from three years was mined for associations. Subsequently, the associations that were discovered were validated separately for the years 2015, 2016 and 2017 using the established thresholds for support and confidence, 10% and 80%, respectively. A detailed description of the *Apriori* algorithm-based association rule mining approach used in this study has been described elsewhere (Agrawal et al., 1993). Association rules analysis was conducted in the R *arules* package (v. 3.4.3) (Hahsler et al., 2006).

Poisson regression tree analysis

A non-parametric and non-linear regression tree modelling approach was used to identify explanatory variables associated with each of the ten outcome variables. A tree-based approach with recursive partitioning of the sample where categorisation was based on data homogeneity within the partition in regard to the outcome variable was used for identification of risk factors, as has been demonstrated in the context of public health (Morgan, 2014). Two Poisson regression tree models were fitted to each of the ten outcomes. Given the multilevel organisation of the data, the first regression tree model was generated including random effect cluster identifying variables (farm and shed identifiers). The second regression tree model was run omitting cluster identifying variables. The two regression tree models therefore aimed to select an inclusive list of explanatory variables both correlated and uncorrelated with hierarchical cluster identifiers. Explanatory variables whose inclusion had the lowest sum of squared error (SSE) were isolated as tree nodes and selected for the next stage of analysis. A detailed description of the method is available elsewhere (Breiman et al., 1984).

In regression tree analysis two-way interactions were suspected when branches subdividing a higher-level node had explanatory variables at the lower level (Camp and Slattery, 2002). Outcome variables were modelled using Poisson methods in the *Rpart* package in R software as condemnation counts per 1,000 slaughtered broilers, with the size of the broiler batch as an offset variable (Therneau and Atkinson, 2008). No pruning, stopping criteria or limits to the depth of the trees were specified in analyses in addition to default (Therneau and Atkinson, 2019).

<u>*Multivariable Poisson regression analysis*</u>

Explanatory variables were identified in multivariable poison regression models fitted separately for each of ten condemnation outcomes. Models were then compared to determine factors that were common to multiple condemnation categories. Poisson regression models were fitted in STATA version 13.0 (Stata, 2013) using a manual backwards elimination procedure (Wald's test p-value <0.05). Collinearity between explanatory variables was suspected (X^2 test, p-value <0.05) and assessed using a 10% change in standard error as a cut-off value, and, if identified, a variable with a higher measure of effect estimate was retained in the analysis. The unit of analysis was the number of whole or partial carcass condemnations in a batch of broilers per 1,000 slaughtered birds, with the number of broilers in a batch as an offset. Random effect intercepts were introduced to account for a farm- and flock-level clustering of broiler batches. Interactions between explanatory variables selected from Poisson regression tree analysis were reported and retained in the final models if the p-value of the likelihood ratio test was <0.05. The fit of the final models was assessed by evaluating the difference between observed and predicted values, and by assessing R squared, a value ranged from 0 to 1, which was used to indicate the model fit. The higher the R-square, the better the model fitted the data. Any missing data were omitted from analyses.

3. Results

3.1. Sampled population and descriptive statistics

Retrospectively collected condemnation data

55,918 broiler batches were slaughtered by the integrator in 2015-2017. The most prevalent condemnation categories were ascites and abnormal colour (Fig. 1). Consideration of the historical condemnation records revealed that the median number of broilers per batch was 5,700, with a range of 700-11,000. 99.3% of batches had two or more conditions leading to condemnation, with only 0.6% (338) of batches free from diagnosed conditions. Condemnation due to a single condition was reported from just 0.1 % (83) of batches (Fig. 2). The most common number of co-morbidities within a batch was either ten or eleven conditions (Fig. 2).

Data from the prospective longitudinal study

Data were collected from a total of 3,354,747 broiler chickens, produced in 115 sheds on 49 farms and processed in [illegible]39 batches. Thus, 49 farms completed the questionnaire at least once, with an overall response rate of 59%. Only 15 farms responded in all four data collection rounds. The study sampled circa 2.7% of all broilers processed by the company during the study period. The median size of a broiler batch in the study was 6,000 broilers, with the smallest batch found to include 146 and the largest 9,758. The median number of sheds on the sampled farms was four (minimum two and maximum 14 sheds).

The frequency of each of nine individual condemnation outcomes per thousand slaughtered broilers and the composite category for all nine is presented in Table 3. The composite incidence of any of the nine outcomes combined was 14.4 whole or partial condemnations per 1,000 slaughtered broilers. The three most frequent individual condemnation categories were ascites, abnormal colour and hard breast. Co-occurrence of condemnation outcomes was high, with 88% of broiler batches showing condemnation due to seven, eight or nine condemnation outcomes.

Associations between condemnation categories

Association rules analysis generated eighteen association rules. These were composed of nine condemnation categories: ascites, abnormal colour, perihepatitis, cellulitis, hard breast, tumours, dead on arrival, partial condemnation of liver only (perihepatitis) and heart only (pericarditis). Focused consideration of the nine morbidities identified a complex network of associations. These represented conditions that occurred in batches at a median frequency or below and at a higher frequency than the median formed two independent networks of associations, demonstrating complicated interactions between the categories and relevance of ascites and abnormal colour with links to multiple association rules (Fig. 3).

The most prevalent combination of morbidities was observed in 17% of broiler batches and included abnormal colour, perihepatitis and ascites. The most strongly associated rule indicated that 86% of batches with condemnations for perihepatitis, tumours, and abnormal colour also had condemnations for ascites. When association rules analysis was carried out separately on data from three successive years (2015-2017), the composition of the rules and list of conditions remained stable, with only a minor change in support or confidence for each of the rules over the three years.

Factors associated with condemnation outcomes

A total of 61 explanatory variables were selected as predictive of the nine individual and one combined condemnation outcomes in regression tree analysis (Fig. 4). The highest number of variables per outcome was 18 and the lowest was 8. Farm and shed effects, and the effect of catching team was associated with all ten outcomes. The next most commonly associated explanatory variable was the type of broiler removal (thinning and clearing). In total, 31 explanatory variables were found to be associated with two or more condemnation outcomes in Poisson regression tree analysis.

Nine explanatory variables were found to be independently associated with two or more individual condemnation outcomes after adjusting for the effect of other explanatory variables in multivariable Poisson regression models (Table 4). Results of multivariate regression models for each of ten considered in this study outcomes are presented in supplementary materials (Table 1 to 10). One variable was related to parental flock characteristics, three variables were related to broiler flock-level characteristics, three were relevant to depopulation and transport, and two were related to slaughterhouse practices. Five of the explanatory variables common for two or more condemnation outcomes displayed a unidirectional effect on condemnation outcomes (Table 4). Four of the variables displayed a contrasting effect, being both risk and protective factors for different condemnation outcomes. For example, parental flock age at the time of lay displayed an association with increased condemnation for cellulitis (Rate Ratio (RR) 1.18, ranging from 8% to 27%), but a decrease in liver only condemnation (RR 0.83; between 8% and 25%).

4. Discussion

Farmed broiler chickens are raised and processed in largely homogeneous units. Pathologies acquired during production and processing that are relevant to animal health and welfare, food safety and quality are identified during meat inspection at the end of the production cycle, generating broiler batch-level multimorbidity reports. Control strategies that can influence several condemnation conditions are highly desirable for broiler production settings. An analytical approach to inform the development of such integrated strategies needs to prioritise between multiple pathologies and can benefit from identification of relevant risk factors. Here, multiple morbidities were recorded in meat inspection data at the broiler batch-level. Associations were determined between condemnation categories that were co-diagnosed in broiler batches and shared production chain factors were identified.

Common co-occurring morbidities are likely to incur high costs to broiler producers. Initially, nine of 23 meat inspection morbidities were found to co-occur in a high proportion of broiler batches. The network of associations included condemnations due to ascites, abnormal colour, dead on arrival, tumours, perihepatitis, hard breast, cellulitis, liver only and heart only morbidities (Fig. 3). The associations were dominated by ascites and abnormal colour, perhaps as a result of their high prevalence. In addition to their prevalence, the central role of ascites and abnormal colour could be explained biologically as both conditions can affect the general health status of broilers, predisposing them to other morbidities. Ascites is a metabolic condition that has been associated with genetic selection of broilers for high growth rate, resulting in circulatory deficiencies and has previously been linked to the presence of pericarditis (Olkowski et al., 2003; Baghbanzadeh and Decuypere, 2008) Abnormal colour, along with perihepatitis and pericarditis, could be a result of septicaemia associated with the presence of pathogens (Fisher et al., 1998). The high prevalence of ascites and abnormal colour detected in our study agreed with a study by Part et al. (2016). No previous research has identified groupings of morbidities around circulatory deficiency (ascites) or infection-related (abnormal colour) conditions, indicating a requirement for further investigation.

The second stage of analysis identified risk factors common to several meat inspection outcomes, focusing on nine associated condemnation categories. Although no risk factors were found to be consistent across all nine, some were associated with more than one category. Notable examples included weight at slaughter, identified as a risk factor in two of the nine final individual models (ascites and hard breast), as well as persisting in the model for composite condemnation inclusive of all nine categories combined. This negative effect of weight at slaughter has previously been linked with all-cause condemnation, as well as hock burns, ascites and dead on arrival (Haslam et al., 2007, 2008; Lupo et al., 2009). The association between weight and condemnation for ascites could be explained by the increased growth rates of broilers that reach a higher final weight. A high growth rate has been shown to induce a higher demand for oxygen, which in turn leads to the development of ascites through chronic hypoxia in fast-growing birds (Julian, 1998).

Broiler chick weight at seven days of age was found to be a risk factor for condemnation due to abnormal colour and heart only categories. Faster growing broilers could be at risk of hypertension-induced right ventricular failure, which can be a precursor of ascites (Julian, 2000). However, birds that had not developed pronounced signs of ascites could have been placed into the partial condemnation category, heart only. The effect of increased weight in early life has not been reported previously to be associated with condemnation for abnormal colour. Abnormal colour could be linked to septicaemia and might be associated with decreased health of broilers due to other conditions associated with high growth rate (Fisher et al., 1998). More specifically, the negative effect of high growth rate on ascites and leg weakness have been reported before, while sudden death syndrome has also been associated with rapid juvenile growth in broilers (Wise, 1975; Kestin et al., 1999; Julian, 2000). Measures to control early growth rates could limit the negative effects of increased seven day weight on the composite condemnation complex which includes abnormal colour, heart only, ascites and hard breast, although the economic consequences of control versus reduced condemnation should be assessed.

Broilers slaughtered and processed during the night shift were at the highest risk of condemnation for cellulitis and tumours. Although the effect of a slaughterhouse on condemnation outcomes for cellulitis has been reported previously, the difference was attributed to between slaughterhouse variation (St-Hilaire and Sears, 2003). Our study, conducted on broilers slaughtered in one slaughterhouse, has identified notable variation in condemnation for cellulitis and tumours between shifts within the same slaughterhouse. In line with the previous research, the variation detected in condemnation rates between shifts could be attributed to inconsistencies in evaluation criteria used by inspectors working in either day or night shifts (Bremner, 1994; St-Hilaire and Sears, 2003; Lupo et al., 2008). Comparison between processing lines revealed the influence of environmental slaughterhouse characteristics on ascites, as well as composite condemnation. Broilers slaughtered and processed in the second processing line were at higher risk of condemnation. This could be explained by specific settings of the processing line in regard to the birds' size oras identified by Lupo et al., the speed of line (2009). However, no interactions or confounding effects of other explanatory variables were identified in the final multivariable models; for example with weight or age at slaughter. The identified effect of slaughterhouse characteristics supports the need for harmonisation and evaluation of inspection practices.

Birds transported in higher numbers per crate had a lower incidence of condemnations for ascites, abnormal colour and hard breast. Since the company uses a standard size crate, the number of broilers per crate may have provided a proxy measure of variation in transportation stocking density. In some instances broilers were transported at lower than target numbers per crate, thus identifying a further need for standardisation. Intriguingly, results of the analysis suggested a protective effect against condemnation for ascites, abnormal colour and hard breast categories. To our knowledge, no effect has been reported of an association between density in transport crates and these three condemnation categories. The occurrence of condemnation categories such as ascites has been associated with faster-growing chickens. It is possible that higher numbers per crate may have reflected smaller, slower growing individuals with a lower risk of developing ascites. Previous research has found a higher crate stocking density to be a risk factor for dead on arrival, which was not identified in the current study (Nijdam et al., 2004; Chauvin et al., 2011). The apparently protective effect of higher broiler density in transport crates was surprising, given its potentially negative consequences to broiler welfare. We can speculate that the protective effect associated with a higher number of birds in transport crates could relate to reduced stress associated with decreased movement. Further investigation into the effects of density during transportation could be warranted by this finding.

A number of factors were found to associate with varied effects on different condemnation outcomes, being a risk factor for some but showing a protective effect against others. These factors were age of parental flock at the time of lay, *Campylobacter* level in a batch, and type of birds' removal from the farm. Increasing parental age was associated with increased incidence rates of condemnation for cellulitis and decreased incidence rates for liver only. To our knowledge, previous research has not reported an effect of parental age on subsequent condemnation outcomes. Nonetheless, a number of studies have reported likely causative links between parental age and outcomes such as broiler chick performance and characteristics (Shim et al., 2008; Yassin et al., 2009; Ulmer-Franco et al., 2010), possibly influenced by parental immunocompetence.

The incidence rate for hard breast and dead on arrival varied between batches caught and loaded into transport crates by different teams of broiler catchers. Previous research has aimed to compare manual and mechanical methods for catching. Manual catching has been linked with lower levels of condemnation for dead on arrival when compared to mechanical catching, with some variation (Ekstrand, 1998; Nijdam et al., 2005). The influence of catching and loading could be linked to the corresponding levels of stress induced by the practices. However, stress indicators were not found to differ between the two catching methods (Nijdam et al., 2005). Thus, variation identified between teams of manual catchers could indicate the need for more consistent application of good practices associated with catching.

The level of *Campylobacter* spp. detected in a broiler batch was associated with increased condemnation rate for tumours and a decreased rate for composite condemnation. While there is no evidence of a direct causative link between *Campylobacter* infection and the development of tumours, it is possible that both features might have similar drivers. It is important to note that the type(s) of tumours were not recorded and no clinical cases were available for comparison, precluding more detailed analysis. A previous study of the occurrence of tumours in broiler chickens identified seasonal trends and suggested an association with environmental factors (Hafner et al., 1993). The incidence of *Campylobacter* infection has previously been found to peak in the summer, in contrast to tumours, when environmental factors were again suggested to play an important role in the occurrence of both conditions (Hafner et al., 1993; Powell et al., 2012). The negative association of high levels of *Campylobacter* measured in shed-level environmental samples from broiler batches with total condemnation outcomes could be related to increased mortality in broiler flocks with high *Campylobacter* prevalence (Powell et al., 2012). *Campylobacter jejuni* has traditionally been considered to be commensal in chickens, although evidence is mounting of a pathogenic effect in modern fast-growing broilers (Humphrey et al., 2014). Increased mortality of weakened or immunocompromised chickens could reduce the number of potentially morbid birds reaching slaughter, possibly reducing total condemnation.

The timing of broiler removal from the farm was found to decrease the incidence of dead on arrival when final depopulation (i.e. clearing) was compared with partial depopulation (i.e.

thinning). The opposite effect was observed on condemnation incidence for heart only (partial condemnation due to pericarditis), perihepatitis, tumours and composite condemnation, showing an increased incidence from chickens at final depopulation. To our knowledge, the effect of type of removal on condemnation incidence has not been reported before. Broilers removed during final depopulation are likely to be older with a higher live weight compared to individuals removed earlier during partial depopulation. Similar to our findings, in a French study, higher overall condemnation rates were observed in birds reared longer to a higher final weight (Lupo et al., 2009), likely permitting more time for condemnation features to emerge. The lower condemnation rate for dead on arrival during final depopulation has not been described before and was an unexpected finding. However, this could be explained by late feathering in the studied broiler population, with a suggestion in feedback that birds collected at thinning had lower feather coverage (personal communication). The population studied consisted of mixed-sex conventional Ross 308 broilers and the cause(s) underlying this observation was not clear. Thus further research is necessary regarding the possible protective effect of final depopulation on dead on arrival, as well as overall flock quality given its relevance to food safety and economic return.

4.1. Limitations

Although a representative sample of integrator broiler populations was selected accounting for multilevel data structure, there are potential limitations to the research described here. Extrapolation of findings to a wider UK broiler population was not supported by the study design. Similarly, the use of data derived from a single integrator might indicate limited variation in practices and characteristics, possibly reducing the detection of risk factors for condemnation outcomes. However, given the relative homogeneity of conventional broiler production practices, applicability of the study findings to other broiler populations in similar settings is likely to be relevant.

Another potential limitation of the present study was related to its longitudinal nature. Longitudinal data collection permitted assessment of seasonal variation in condemnation outcomes but could have introduced variation in risk factors. Additionally, in this study, the analysis was conducted on nine individual but linked condemnation outcomes, in addition to a composite category of all nine. Comparison of the individual and composite datasets identified different but overlapping sets of risk factors. The absence of a predictive set of variables capable of explaining all of the individual condemnation outcomes is, at least in part, due to heterogeneity of the overall condemnation outcome (Lupo et al., 2009). Nonetheless, our analysis and the previous studies have identified risk factors associated with multiple condemnation outcomes and the composite condemnation outcome (Lupo et al., 2008; Lupo et al., 2009; Lupo et al., 2010). Risk factors which presented with opposing effects for different individual condemnation outcomes were not identified as associated with composite condemnation. Thus, the discovered risk factors might have been associated with either the most prevalent condemnation category within the overall outcome, or be truly associated with a number of condemnation categories. Therefore, our findings support concerns about using grouped condemnation outcome as raised previously (Lupo et al., 2009).

Finally, both protective and risk factors for broiler slaughterhouse condemnation were identified in our study would have limited value for control strategies as not currently amenable to modification. Some of the factors are inherent characteristics of broiler production or animal biology, for example, the age of parental flocks at time of lay might have negative economic effect if modified. Nonetheless, these factors remain relevant to prediction of condemnation levels. For example, broilers removed from a farm during final depopulation can be expected to yield higher levels of condemnation for heart only, as well as pericarditis, perihepatitis, and tumours. Similarly, a higher level of dead on arrival could be expected in broilers removed from a farm during partial depopulation.

4.2. Conclusions

This study provided further evidence for the involvement of multiple broiler production stages in slaughterhouse condemnation outcomes. Multiple factors present in parental flocks, during rearing, transport and slaughter of broiler chickens were identified as associated with two or more condemnation outcomes. Slaughterhouse practices and broiler weight at different production stages were identified as risk factors for multiple outcomes. Slaughterhouse shift, a team of inspectors working either a day or night shift pattern, and line characteristics were associated with increased ascites, cellulitis, tumours and composite condemnation outcomes. Broiler weight was a risk factor for abnormal colour, ascites, hard breast, heart only and composite condemnation outcomes. Further, some factors were found to associate with reduced condemnations such as an increased density of broilers in transport crates. Many of the risk factors identified here may be amenable to modification, supporting a whole production chain approach to studying factors that affect condemnation (Lupo et al., 2010). In the future regular, or even live monitoring of condemnation reports could be used to direct interventions during broiler production to reduce condemnation and improve welfare.

Although this study did not provide evidence to explain associations discovered between all nine target condemnation categories, the information generated can be used to inform strategies to control multiple pathologies that result in condemnation.

Ethical animal research

Consent to collect and use the data in this study was obtained from the broiler integrator company under the data sharing agreement of Industrial CASE BBSRC project BB/L016559/1.

The study was reviewed and granted ethical approval by the Social Science Research Ethical Review Board at the Royal Veterinary College, approval number URN 2017 1683-3.

Conflict of interest

The authors report no conflict of interest.

A Declarations of interest: none.

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Fig. 1. Frequency of condemnation conditions detected in batches of broiler chickens in a commercial integrator slaughterhouse. The percentage of carcasses condemned was calculated for the corresponding conditions throughout the total period of 2015, 2016 and 2017.

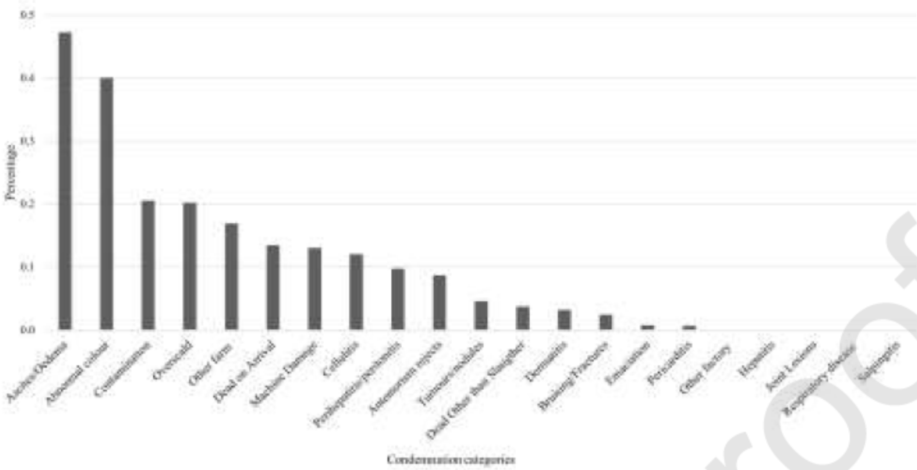

Fig. 2. Batch-level co-occurrence of condemnation categories using 55,918 batch integrator records for 2015, 2016 and 2017, where the occurrence of a condition was negative or positive (at least one condemnation case for a given category in a broiler batch).

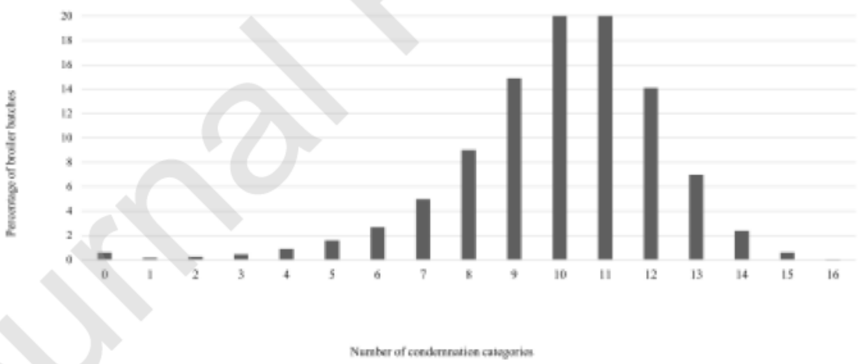

Fig. 3. Networks of morbidities associated in 18 rules generated in association rules analysis with support of 10% and confidence of 80%. The division between rules with conditions identified at below (coded as 0.5; A) and above (coded as 1; B) median values is presented by two distinct networks of associations. Node size: support (0.1-0.175). The intensity of node colour: lift (1.606-1.746)

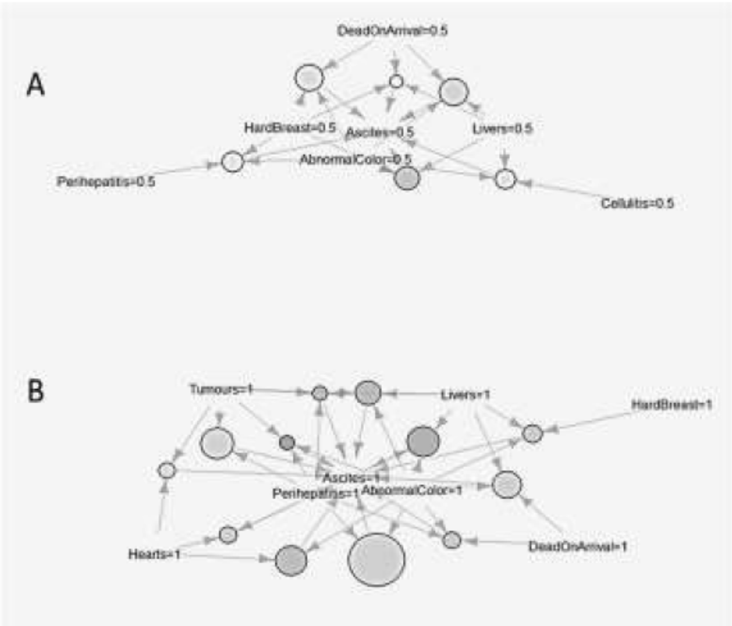

Fig. 4. Explanatory variables found associated with condemnation outcomes. Selection of the variables was made using two Poisson regression trees for each condemnation outcome (with/without random effect of farm and flock).

Table 1. Data collected using a postal questionnaire and routine company and slaughterhouse records.

Farm questionnaire (71 questions)
Farm-level data (20 questions)
• General farm information: water source, water sanitation and acidification, feed source mill
• Biosecurity: hygiene practices, dead bird disposal, control of rodent activity
• Staff: number of personnel, years of experience, training

Shed-level data (14 questions)	
	• General shed information: age of the shed, drinking and feeding system type, ventilation type (location of vents, type of ventilation operation) • Management of the flock: type and amount of bedding material, the addition of bedding, type of lighting, number of dark hours, number of flock visits by the manager
Broiler flock related data (37 questions)	
	• Flock management information: downtime, pre-heating of the shed
	• Broiler related information: heat stress, managers evaluation of chicks/older birds quality, health issues and medication use, veterinary visit, autopsy findings
	• Catching and transportation information: presence of manager during the catch, overalls and gloves change by the catch team, weather conditions
Company records (70 questions)	
Farm-level data (10 questions)	
	• Farm size, number of sheds, distance to a slaughterhouse, type of ownership, use of farm for other animal species (e.g. turkey)
Flock-level data (38 questions)	
	• Broiler related information: number of chicks placed, age of parent flock, source hatchery, number of farm culls, mortality, weight
	• Flock management related information: maximum stocking density, dates of thinning and clearing, age and weight of chickens at removal, number of days between removals, quality of litter
Batch-level data (22 questions)	
	• Catchers team identity, number of birds per batch, time of catch start, time between catch and slaughter, time in transit, time in lairage, processing speed, number of birds per crate, level of *Campylobacter* (assessed using quantitative PCR), slaughter line, time of slaughter

Table 2. Health and welfare-related condemnation categories recorded at the integrator company slaughterhouse. Mechanical processing-related condemnations are not included.

Code	Integrator health and welfare-related condemnation categories (category type)	Description
ABN	1. Abnormal colour	Septicaemia, toxaemia (Fisher et al., 1998)
IR	2. Intake runts	Small birds identified and rejected at intake (Cargill, 2010 -a)
EVR	3. Evisceration runts	Small birds identified and rejected at evisceration
AST	4. Ascites	Accumulation of fluid in the abdominal cavity as a result of circulatory system malfunction (Cahaner, 2011)
BRU	5. Bruising and Fractures	Accumulation of blood. Broken bones (Löhren, 2012)
CEL	6. Cellulitis	Inflammation of connective tissue of the skin (Fallavena et al., 2000)
SKN	7. Skin other	Other skin conditions not classified under "dermatitis"
DER	8. Dermatitis	Inflammation of the skin (Menzies et al., 1998)
FOL	9. Folliculitis	Inflammation of skin follicles, sub-type of dermatitis (Meena et al., 2015)
DOA	10. Dead on Arrival	Dead birds found during shackling (Pagazaurtundua A., 2010)
EMA	11. Emaciation	Decreased muscle tissue, low weight (Cargill, 2010 -a)

HEP	12. Hepatitis	Inflammation of the liver (Cargill, 2010 -b)
JNT	13. Joint Lesions	Joint inflammation, bone deformities (Pearson and Carnoky, 2010)
HB	14. Hard breast	Hardening of breast muscle due to myopathy (Carnoky et al., 2010)
JND	15. Jaundice	Yellow colour of the skin due to bilirubin accumulation (Carnoky et al., 2010)
FOT	16. Oregon, myopathies, etc.	Oregon: green colour of breast muscle. White stripe: white muscle fibres (Carnoky et al., 2010)
PCS	17. Pericarditis	Inflammation of heart membrane pericardium (Cargill, 2010)
Heart only	18. Partial rejection-heart	Rejection of the heart results from identification of pericarditis
PTS	19. Peritonitis	Inflammation within the peritoneal cavity (Beckman, 2006)
PHS	20. Perihepatitis	Inflammation of the liver capsule (Amini et al., 2015)
Livers only	21. Partial rejection-liver	Rejection of the liver results from identification of perihepatitis
RES	22. Respiratory conditions	Inflammation of air sacs (Romero, 2010)
TUM	23. Tumours and nodules	Abnormal tissue growth (Dunn and Pagazaurtundua, 2010)

Table 3. The number and rates of nine individual and combined condemnation outcomes per 1,000 slaughtered broilers. Calculations are presented for 3,354,747 broiler chickens originating from 539 batches, whose data were collected between April 2017 and March 2018.

Condemnation conditions	Number of condemnations	Condemnation rate per 1,000	95% confidence interval
Ascites	15,167	4.5	2.7-7.4
Abnormal colour	11,954	3.6	2.0-6.3
Hard breast	4,979	1.5	0.5-3.6
Dead on Arrival	4,538	1.4	0.3-3.2
Cellulitis	4,293	1.3	0.3-3.2
Livers (partial condemnation)	3,077	0.9	0.2-2.8
Perihepatitis	2,084	0.6	0.1-2.3
Tumours	1,254	0.4	0.1-1.9
Hearts (partial condemnation)	1,007	0.3	0.1-1.9
All nine, combined	48,353	14.4	10.8-19.0

Table 4. Incidence rate ratios for variables associated with two or more condemnation outcomes selected from ten multivariable Poisson regression models (p-value<=0.05) with 95% Confidence intervals in brackets.

Category	Major age of parental flock at time of lay	Level of *Campylobacter*	Weight at 7 days of age	Weight at slaughter	Type of bird removal	Identity of catcher team	Number of birds per crate	Slaughterhouse shift	Slaughterhouse line number
ABN			1.35 (1.23-1.48)				0.85 (0.82-0.87)		
AST				1.44 (1.36-1.53)			0.83 (0.80-0.91)		1.36 (1.25-1.48)
CEL	1.18 (1.18-1.27)							1.84 (1.67-2.02)	
DOA					0.88 (0.82-0.95)	0.997 (0.995-0.999)			
HB				1.78 (1.61-1.96)		1.004 (1.001-1.10)	0.86 (0.80-0.87)		
Heart only			1.41 (1.14-1.75)		2.93 (2.32-3.70)				
Liver only	0.83 (0.75-0.92)								
PHS					2.21 (1.92-2.57)				
TUM		1.09 (1.03-1.14)			1.88 (1.60-2.00)			1.74 (1.51-2.01)	
All nine		0.98 (0.96-0.99)		1.20 (1.16-1.23)	1.27 (1.20-1.33)				1.13 (1.08-1.18)