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Accepted Version

Jones, P. J. ORCID: https://orcid.org/0000-0003-3464-5424, Niemi, J., Christensen, J.-P., Tranter, R. B. ORCID: https://orcid.org/0000-0003-0702-6505 and Bennett, R. M. ORCID: https://orcid.org/0000-0003-3226-8370 (2019) A review of the financial impact of production diseases in poultry production systems. Animal Production Science, 59 (9). pp. 1585-1597. ISSN 1836-0939 doi: 10.1071/AN18281 Available at https://centaur.reading.ac.uk/78999/

To link to this article DOI: http://dx.doi.org/10.1071/AN18281

Publisher: CSIRO Publishing

A review of the financial impact of production diseases in poultry production systems

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The financial impact of production diseases in poultry production systems

Abstract

Whilst the academic literature widely asserts that production diseases have a significant financial impact on poultry propduction, these claims are rarely supported by empirical evidence. There is a risk, therefore, that the information needs of poultry producers regarding the costs associated with particular diseases are not being adequately met.

A systematic literature review of poultry production diseases was undertaken, first to scope the availability of studies that estimate the financial impacts of production diseases on poultry systems and second, based on these studies, estimates were generated of the magnitude of these impacts. Nine production diseases, selected by a panel of stakeholders as being economically important in the EU, were examined.

The review found that the poultry disease literature has primarily an epidemiological focus, with very few publications provideing estimates of the financial impacts of diseases. However, some publications quantified the physical impacts of production diseases and control interventions, e.g. using measures such as output volumes, mortality rates, bacteria counts, etc. Using these data in standard financial models, partial financial analyses were possible for some poultry production diseases.

Coccidiosis and clostridiosis were found to be the most common production diseases in broiler flocks, with salpingoperitonitis the most common in layers. While the financial impact of untreated diseases varied, most uncontrolled diseases were estimated to make flocks loss-making. However, in all cases, interventions were available that signficantly reduced these losses. The review reinforces the concern that the available academic

literature is not providing sufficient information for poultry producers to decide on financially-optimal disease prevention and treatment measures.

Keywords: Poultry diseases; financial impacts; systematic literature review.

1. Introduction

There have been major changes in food consumption patterns in Western countries in the last 20 years, driven by increasing disposable incomes, changing food tastes and evolving health concerns (Traill, et al., 2014; European Commission, 2015). While egg consumption has remained fairly static (FAO, 2016a), there has been substantial growth in demand for poultry meat. Poultry meat is now the largest single source of meat-based protein in the diets of some countries, for example constituting 31% of all meat consumption in the UK and 43% in the USA in 2011 (FAO, 2016b). The chicken meat sector has responded to this increased demand by intensification of broiler production systems, involving more vertical integration, increases in production scale, use of new technologies and higher rates of input use, including higher stocking rates (FAO, 2016c).

A negative side of increasing production intensity has been a rise in the prevalence of so-called ‘production diseases’ in poultry systems. These usually originate from a complex interaction of pathogens, animal genetics and environment, including deficiencies in housing, nutrition and management. Production diseases constitute various infections, but also physical conditions, such as ascites, caused by genetic developments designed to increase physical performance, and physical damage caused by objects, or chemical irritants, in the rearing environment. What these diseases have in common is that, while they may be endemic, even in the wild, they can become increasingly problematic with the intensity of the production system and failures in management (Liverani, et al, 2013).

Production diseases compromise animal health and welfare and generate production inefficiencies, which can reduce profitability, and increase both environmental footprint and levels of antibiotic use. Bennett (2012) has provided a conceptual understanding of the way in which production diseases impact the economics of poultry production systems, i.e. through:

1. Economic impacts internal to the farm:
    - a loss of capital (i.e. animal mortality);
    - reduction in the level of marketable outputs;
    - reduction in (perceived or actual) output quality; and
    - waste of, or higher level of use of, inputs.
2. Economic impacts both internal, and external, to the farm:
    - resource costs associated with disease detection, diagnosis, prevention and control;
    - negative animal welfare impacts (i.e. animal suffering) associated with disease;
    - international trade restrictions due to disease and its control; and
    - human health costs associated with diseases or disease control.
3. Economic impacts external to the farm such as effects on rural economies and tourism.

With producer margins being squeezed by increasing costs and limited opportunity to transmit extra costs to consumers due to lack of market power, plus fierce competition from international suppliers, the response of the poultry industry has been to drive down those production costs that can be controlled, including disease costs (Narrod et al., 2008). To allow the industry to prioritise the most financially beneficial disease prevention and control measures, robust empirical data are required on: the risks posed by various production diseases; the financial impacts of different diseases; and the efficacy of, and financial benefits from, different disease control measures.

It might be be assumed that data to permit financially rational disease management decisions are available in the scientific literature. Much literature on poultry diseases exists, but data for individual diseases is seldom extensive and often lacking a financial dimension. Ubiquitous claims in research papers that particular poultry diseases lead to 'significant' financial impacts are seldom supported by empirical evidence. Consequently, data on the scale of financial losses associated with particular production diseases and the financial case for using control measures, are often lacking. Therefore, unless more informative industry data is available, there may be many poultry producers who are not implementing financially optimal disease prevention and treatment practices through lack of appropriate information. For example, in Denmark, vaccines are widely used to control salpingoperitonitis infections in layers without robust evidence of their efficacy (Christensen, 2016).

The study reported here undertook a systematic literature review to: determine the availability of data on the financial impacts of poulty production diseases; and a synthesis of this data to estimate the financial impacts of a number of production diseases and, where possible, the financial benefits of selected measures to control them. The study also had three sub-objectives. First, to show the relative risks presented by different production diseases, from data on their incidence. Second, to map the nature and distribution of disease costs, by showing where, in the production process, losses are occurring. Finally, to identify gaps in the literature on the financial impacts of poultry production diseases, to help guide future research.

2. Method

2.1 The choice of production diseases

To reduce the scope of the study, the most important production diseases were selected for analysis by a panel of 29 European animal scientists collaborating on the EU-funded PROHEALTH project.These came predominantly from veterinary medicine or animal science backgrounds. Nine production diseases were identified as the most important by virtue of rates of incidence, revenue losses, or control problems, i.e. respiratory diseases (Ascites; Infectious bronchitis), enteric (Coccidiosis; Clostridiosis), locomotory (Tibial dischrondoplasia; Foot pad dermatitis; Keel bone damage), reproductive (Salpingoperitonitis) and other disorders (Injurious feather pecking).

2.2 The systematic literature review -

2.2.1 Introduction

A systematic review was undertaken to identify studies reporting financial or productivity impacts of these nine production diseases/conditions. As a first step, a Web of Science search was undertaken using a tailored search term with keywords to capture:

(i) economic (or financial) studies;
(ii) poultry as study subjects;
(iii) specific production diseases;
(iv) exclusion of topics appearing in searches but not relevant to the review;
(v) exclusions to remove studies based on non-intensive production systems; and
(vi) exclusions by text language, research domain, document type and publication prior to 1995.

Abstracts found through the search were examined to exclude: duplications, those with no physical performance measures or financial data, or were based on modelling studies or reviews. This yielded 64 original studies. To supplement this list, additional publications were found by: reviewing the reference lists of publications already identified; a secondary web search using Google Scholar; website searches of organisations with an interest in poultry health, such as the FAO; and reference lists from recent poultry health research projects. This secondary search yielded a further

65 studies, making 129 in total. These publications encompassed peer-reviewed journals and conference proceedings, as well as 'grey' literature. Few publicatons assessed financial impacts, with most falling into the three categories shown in Sections 2.2.2 through 2.2.4.

2.2.2 Surveys of disease invidence and severity

A few studies surveyed the incidence of production diseases. Incidence, which is the number of (new) disease incidents (or outbreaks) over a specified period of time, can be viewed as an indicator of risk. Incidence might be reported for a particular flock, or as an average across flocks (e.g. average annual incidence). In the studies reviewed, flocks were generally only deemed to have experienced a disease outbreak when symptoms met a given severity criterion i.e. they either exhibited clinical symptoms, or where subclinical disease resulted in fiancial impacts. As we were only interested in disease episodes that cause financial losses, the analysis of incidence here was limited to those surveys where this criterion was explicitly used.

2.2.3 Studies exploring the impact of uncontrolled diseases on production

In this type of experimental study, birds could be deliberately exposed to a disease in either a controlled, or uncontrolled way. In the latter case, ambient levels of disease prevailed and therefore disease prevalence or severity was sometimes not elevated at all. Some of these studies employed a protected (or disease free) control group, while others did not.

2.2.4 Studies exploring the efficacy of measures to control production diseases

Intervention studies were the most common type of study in the reviewed literature. These involved trials of wide-ranging scale, from a few dozen birds to tens of thousands of birds across many poultry businesses. These studies had a variety of formats, depending on the:

- presence of a control group;
- presence of replicates;
- the number of interventions tested; and
- the level of control of environmental (rearing) conditions.

Studies with no control groups were excluded from the assessment. Where there were replicates of trials, averages over the replicates were calculated. When multiple, similar, interventions were used, for example several types of vaccine, an average over these interventions was taken. When multiple interventions were very different, for example contrasting a vaccine against a dietary nutrient, they were treated as separate interventions. When studies manipulated environmental conditions, in addition to target interventions, such as wetness of litter, then an average for the intervention over the multiple environmental conditions was estimated.

2.3 The standard financial models

Because financial data were rarely provided, the costs of diseases were estimated from data on changes to productive parameters (i.e. FCR, mortality and output volumes), using spreadsheet-based standard financial models for poultry enterprises. These were based on published data for market returns and production costs for EU 'average' conventional broiler and layer enterprises for 2013 (Appendix A).

2.5 Weighting of data

Recognizing that greater confidence can be placed on trials conducted on larger populations of birds, a weighting system was used in estimating averages across replicate trials. As studies often didn't state the exact number of birds in a trial, the value of the weights increases with size ranges using a geometric progression with a common ratio of two. By this means, data from experiments with up to 1,000 birds were given a weight of one, 1,001-10,000 birds had a weight of two, 10,001-25,000 birds a weight of four, and more than 25,000 birds a weight of eight.

3. Results

3.1 The number of relevant studies identified from the systematic literature review

Table 1 lists the number of relevant studies identified for the nine study production diseases, classified by the type of intervention used. Studies reporting no interventions in Table 1 either examined the impacts of the uncontrolled disease, or were surveys of disease incidence.

Table 1. The number of publications found reporting the impacts of poultry production diseases and/or impacts of interventions to control them.

	Type of prevention/control intervention					
	None	**Anti-microbials[1]**	**Vaccination**	**Housing**	**Other[3]**	**Total studies[2]**
Respiratory diseases						
Pulmonary hypertension syndrome (ascites)	1	-	-	-	9	10
Infectious bronchitis (IB)	14	-	5	-	-	19
Enteric diseases						
Coccidiosis	1	7	8	-	-	16
Clostridiosis (*C. perfringens, C. septicum*)	1	10	3	-	1	15
Locomotory diseases						
Tibial dischrondoplasia	3	-	-	4	7	14
Foot pad dermatitis	3	-	-	-	12	15
Keel bone damage	10	-	-	3	5	18
Reproductive disorder						
Salpingoperitonitis syndrome, (colibacillosis)	9	1	-	-	-	10
Other disorders						

Injurious feather pecking	7	-	-	4	1	12
Total	45	18	16	11	35	129

[1] For either prophylactic or curative treatment.

[2] Some studies had multiple interventions, so the total number of studies may not equal the number of interventions.

[3] 'Other' usually involves changing parameters in the rearing environment, such as temperature, or humidity.

3.2 Disease incidence

This data came from studies ranging from large-scale surveys to small-scale laboratory trials. Because of the dominance of small-scale studies in the literature, the estimates in Table 2 should be treated with caution. Coccidiosis and clostridiosis would seem to be present in 90 - 100% of poultry flocks (Williams, 1998; Miller et al., 2010). There is a far greater incidence of the subclinical forms of these diseases, but these are only included in the incidence estimates where they cause productivity losses. The lowest reported disease incidence (at 5%) was reported for ascites, but most production diseases appear to have a reported incidence of over 30% of flocks.

Table 2. The incidence of production diseases and sources of this data

		Incidence (% of flocks)	**Sources of data**
Ascites	Broiler flocks	5	Hassanzadeh et al. (2005); Hassanzadeh et al. (2008); Maxwell and Robertson (1998)
Coccidiosis	Broiler flocks	90-100	Williams (1998, 1999)[1]
Clostridiosis	Broiler flocks	90-100	Miller et al. (2010)[1]
Footpad dermatitis	Broiler flocks	41.1	Allain et al. (2009); de Jong et al. (2014); Pagazaurtundua and Warriss (2006)
Tibial dyschondroplasia	Broiler flocks	35.6	Edwards (1990); Edwards and Sorensen (1987); Leeson et al. (1995); Lilburn and Lauterio (1989); Lui et al. (1992); Petek et al. (2005); Trablante et al. (2003); Yalcin et al. (2007)
Salpingoperitonitis	[illegible]	49.5	Fossum et al. (2009)[2]

Injurious feather pecking	35	Lambton et al. (2013)

[1] Exact estimates of incidence for coccidiosis and clostridiosis are unavailable but sources indicate these infections are close to ubiquitous.

[2] Estimate of incidence of coliobaccilosis i.e. e-coli infections.

3.3 Mortality rates

Financial impacts resulting from elevated bird mortality comes from: loss of sales; expenditure on housing, feed and health care for birds that subsequently die; and the cost of disposal of carcasses. Once a disease is present in a flock, mortality rate is determined both by the severity of the disease challenge, and other factors such as the type of bird, breed, age at end of productive life-cycle and housing and production system, e.g. free-range. In an average commercial setting, with 'standard' disease management practice, cumulative mortality in layers, from all causes, ranges from 6 - 11%, with an average of 7.7% (van Horne, 2014; Weber et al., 2003; Merle et al., undated; Vitse et al., 2005; and Bell, 2012). Cumulative mortality in broilers is somewhat lower, ranging between 4 - 6% with an average of 4.7% (Havenstein et al., 2003; ACP, 2006; Gocsik et al., 2014; and van Horne and Bont, 2014). Table 3 shows the change in rate of mortality resulting from uncontrolled production diseases that are classified in studies as severe, i.e. where they have measureable financial impact. Also shown are the ranage of mortality values (in parentheses) found in the literature, where more than one usable estimate is available.

Table 3. Impact of severe uncontrolled production disease on flock mortality rates

	Mortality change (%) (range %)	**Sources of data**
Broilers		

Tibial dischondroplasia	+1	Morris (1993)
Acites	+36.3 (15.2 – 68)	Acar et al. (1995); Arce-Menocal et al. (2009); Camacho-Fernandez et al. (2002); Izadinia et al. (2010)
Clostridiosis	+336 (45.4 – 1500)	Lovland and Kaldhusdal (2001); Miller et al. (2010);Tactacan et al. (2013); Zhang et al. (2010)
Footpad dermatitis	+12.7 (-1 – 87.5)	Bilgili et al. (2009); Cengiz et al. (2011); de Jong et al. (2014); Ekstrand et al. (1997); Martland (1985); Mayne et al. (2007); Taira et al. (2013); Wang et al. (2010)
Laying flocks		
Keel bone damage	+71.5 (65.1 - 77.8)	Nasr et al. (2013); Petrik et al. (2015);
Salpingoperitonitis	+57	Jordan et al. (2005); Medina (2008), Thøfner et al. (2015)

Note: Change in mortality is the change to the base, or 'normal', mortality rate resulting from uncontrolled disease.

Note: Coccidiosis, Salpingoperitonitis and Injurious pecking are omited from the table due to lack of data.

Mortality impacts vary considerably between, and within, production diseases, and disease-driven mortality rates much higher than those in Table 3 have been observed in commercial practice. However, the headline observation is the paucity of studies on the mortality impacts of specific diseases in the literature. This problem is compounded by methodological weakness that affect the available data, i.e. some studies either have no experimental control, or they have a disease-challenged control, rather than a true (disease free) control. The lack of robustness in the available data is exemplified by the mortality impacts estimated for keel bone damage, which are considerably higher in the studies cited than have been observed by the authors in commercial farming practice.

3.4 Loss of physical outputs

Production diseases can lead to financial losses through reductions in the physical output from flocks (see Table 4). In broilers this can take the form of reduced terminal weight (or rather, a longer growing period to reach the desired weight, requiring more feeding and less efficient utilization of resources). In layers this would mean reduced egg numbers, but also impairment of output quality. Loss of quality in broilers means broken bones, damaged or discoloured muscle, or skin burns, leading to carcass downgrades, or trimmings. In layers, this is experienced as smaller or mishapen eggs, thin shells and colour change, resulting in downgrades or rejections.

Reviewed studies report reductions in terminal body weight in broilers range from zero for ascites (although Swayne, 2013, suggests some weight loss is possible), to a high of 17.7% for coccidiosis. There is a relatively high reported loss of body weight from tibial dyschondroplasia. This effect is likely due to the fact that the condition can cause considerable pain, and birds in pain move less and consume less food.

Table 4. Impact of severe and uncontrolled production disease on physical outputs

Broilers	**Live-weight (% change) (range)**	**Carcass downgrades (% change) (range)**		**Sources of data**
Tibial dischondroplasia	-10	<1		Burton et al. (1981); Edwards and Sorensen (1987); Morris (1993)
Acites	0	N.A.		Acar et al. (1995); Arce et al. (1992); Arce-Menocal et al. (2009); Camacho-Fernandez et al. (2002); Izadinia et al. (2010); Kalmar et al. (2013); Khajali et al. (2007); Maxwell and Morris (1992); Rincon (2000); Robertson (1998)
Clostridiosis	-1.24	N.A.		Lovland and Kaldhusdal (2001)
Coccidiosis	-17.7 (-17.3 - -18.1)	N.A.		Abdelrahman et al. (2014); Li et al. (2005)
Footpad dermatitis	-7.3 (0.8 – -14.6)	<1		Cengiz et al. (2011); de Jong et al. (2014); Martland (1985)
Laying Flocks	**Egg numbers**	**Egg weight**	**Egg quality**	

Keel bone damage	-3.5 (-1.2 - -5.7)	-3.2		Nasr et al. (2012); Nasr et al (2013)
Infectious bronchitis	-32.9 (-3 - -50)	-8.7 (-7.3 - -11.36)	N.A.	Bisgaard M. (1976); Muneer et al. (1986); Muneer et al. (1987); Ignjatovic and Sapats (2000); Muneer et al. (2000)
Salpingoperitonitis	N.A.	N.A.	<1	Bisgaard and Dam (1981)
Injurious feather pecking	-5.1 (-2.6 - -7.5)	0	0	Glatz (2001); Hagger et al. (1989); Peguri and Coon (1993); Leeson and Morrison (1978)

Note: N.A. means that suitable data are not available.

Disease impacts on laying flocks (number of eggs) rangese between 3.5% and 32.9%, although greater losses may be observed in commercial practice. The impact of keel bone damage and injurious pecking on egg production should be low, unless birds contract secondary infections. In the case of feather pecking, feather loss means elevated loss of body heat, so that birds must eat more food to regulate body temperature and continue normal egg laying. While the impacts of infectious bronchitis can be severe, these effects last for only a small part of the productive life of a hen, typically 1-8 weeks. If a disease does not kill a hen, it will recover, and so, typically, will the laying percentage, although productivity may not always recover to pre-disease levels (Ignjatovic and Sapats, 2000; and Bisgaard, 1976). Based on available data, infectious bronchitis has the most significant impact on egg downgrades.

3.5 Impaired feed conversion ratio

All production diseases, if severe enough, impair birds' FCR i.e. they lower feed conversion efficiency. Where the bird cannot compensate by eating more, this can lead to loss of physical output. Where additional food is available and the bird has the capacity to consume it, physical outputs need not be reduced, but financial losses will still be experienced due to elevated feed consumption. Reductions in FCR ranged from zero for ascites to reductions of 25.9% for severe feather pecking (Table 5).

Table 5. Impact of severe, uncontrolled, production disease on the feed conversion ratio (FCR)

	Reduction in FCR (%) (range)	Sources of data
Broilers		
Acites	0	Acar et al. (1995); Arce et al. (1992); Arce-Menocal et al. (2009); Camacho-Fernandez et al. (2002); Izadinia et al. (2010); Kalmar et al. (2013); Khajali et al. (2007); Maxwell and Robertson (1998); Morris (1992); Rincon, (2000)
Clostridiosis	16.4 (-3.7 – 70.5)	Lovland and Kaldhusdal (2001); Miller et al. (2010); Tactacan et al. (2013); Zhang et al. (2010)
Coccidiosis	17.7	Abdelrahman et al. (2014); Li et al. (2005)
Footpad dermatitis	3.3 (1.06 – 4.35)	Cengiz et al. (2011); de Jong et al. (2014)
Laying flocks		
Injurious feather pecking	25.9 (-5.1 - -49.7)	Glatz (2001); Leeson and Morrison (1978); Peguri & Coon (1993)

Note: Suitable data are not available for Tibial Dischondroplasia, Keel bone damage, Infectious bronchitis and salpingoperitonitis.

3.6 Financial impacts of uncontrolled production diseases

The financial impacts of these diseases were estimated by applying percentage changes in physical outputs to the standard broiler and layer financial models (Appendix A). On the few occasions where data were available from the studies on changes to input costs resulting from the diseases, or interventions, these were also used in the financial models. For six of the diseases there were sufficient data to undertake financial analyses, while for three there were not. In Figures 1 and 2, the darker shaded bars represent the financial losses per bird, averaged over the flock, arising from the uncontrolled diseases and the lighter bars show the losses that would be incurred after applying the best available interventions to control them. Not surprisingly, average losses for layers are higher than broilers because layers have a longer productive life (around 56 weeks (RSPCA, 2016) and thus generate more revenue. Broilers are usually slaughtered around 6-7 weeks in the EU and USA (EFSA, 2010; National Chicken Council, 2016), depending on growth rates and desired slaughter weights.

Uncontrolled clostridiosis caused the greatest reported losses, at around €0.32 per bird averaged over the flock, while losses from uncontrolled coccidiosis amounted to €0.21 per bird. Based on the financial model used here, confirmed by anecdotal industry evidence, the net (profit) margin for a typical commercial broiler enterprise in the EU in 2013 was low, at around 10 Euro Cents per bird. With margins as tight as this, all of the production diseases costed here would, when unconstrained, make affected flocks loss-making.

Based on the standard financial model, laying hens typically generated a margin of around €6 per bird in 2013. Figure 2 shows that, among the studied diseases, keel bone damage causes the largest financial losses in laying hens, at around €3.5 per bird averaged over the flock. However, this result should be treated with some caution in view of the doubts raised above over the scale of mortality losses reported for this disease.

A number of possible disease costs have not been accounted for, due to lack of data. Typically, there are no data available from most disease impactstudies on labour, vet and medicine costs, additional carcass disposal costs, or costs associated with the disruption of normal husbandry practices resulting from diseases, such as delays to thinning and depopulation to allow extra time for broilers to reach target weight. Also not reported are losses from increased heterogeneity of broiler weights in a cohort, meaning that a greater proportion of birds would fail to meet buyer requirements for permissible weight range and would have to be sold at lower prices, often through alternative marketing channels.

Figure 1. Financial losses due to four production diseases (controlled and uncontrolled) in broiler flocks.

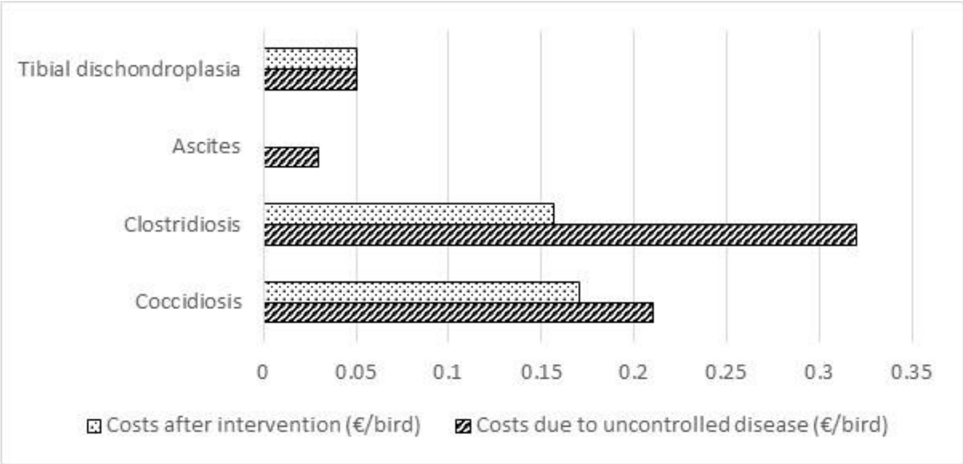
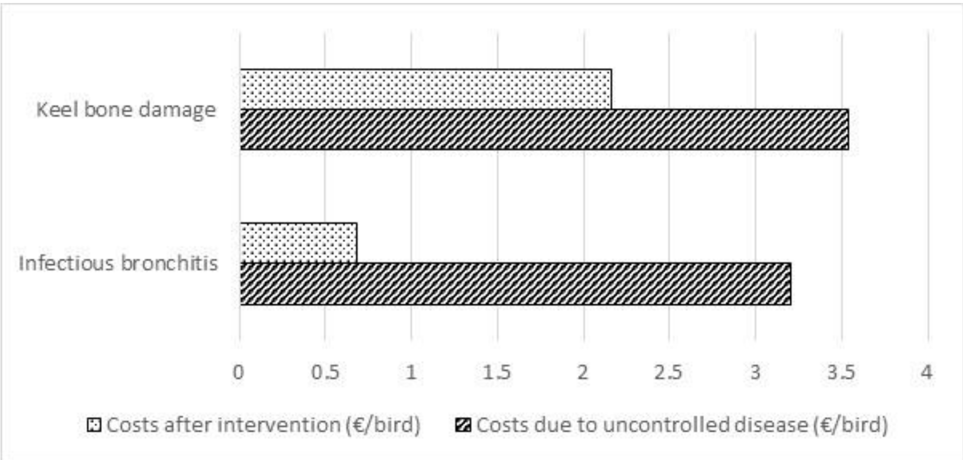


Figure 2. Financial losses due to two production diseases (controlled and uncontrolled) in laying flocks.



3.7 The efficacy of interventions

Interventions to control production diseases in poultry are of two types, both adding to production costs: treatment and prevention measures. Once a disease outbreak has occurred, producers react with one or more courses of treatments, often with veterinary support. Because many diseases are endemic, and difficult or expensive to control once established, producers sometimes deploy preventive measures to try to reduce the risk of outbreaks and/or their severity. The cost of therapeutic treatments can be reduced if treatment begins early in a disease outbreak and so, producers may also increase expenditure on health monitoring to identify early signs of disease.

As Table 6 shows, many types of intervention have been evaluated in the literature, although there are few studies for any particular intervention. There is some heterogeneity within type of intervention studied for each disease. For example, in the anti-microbial category, treatments might be dietary supplements, probiotics, bacteriophage therapy, or antibiotics, with variation within these categories based on compounds or brands used, and concentrations of active ingredients. The data presented in Figures 1 and 2 represent the single most efficacious intervention reported in the literature for each disease. These estimates provide a sense of the higher end of the achievable levels of control that might be expected in a commercial setting.

Figures 1 and 2 show that there are considerable differences between these diseases in terms of both the financial losses caused when uncontrolled, and the extent to which interventions can reduce these losses. Tibial dyschondroplasia, for example, causes relatively small financial losses, but these are relatively difficult to eliminate. Conversely, diseases such as clostridiosis and infectious bronchitis, while resulting in very high financial costs when uncontrolled, can be reduced effectively through interventions. The diseases that would seem most problematic are those, such as keel bone damage, which lead to high financial costs when unconstrained and which resist attempts to control them. Based on this analysis, coccidiosis appears to fall into this class, with lower efficacy of interventions than for other diseases. However, producers report that both vaccines and anti-microbials offer significant means of disease control in a commercial setting.

Table 6. Types of intervention to control production diseases from the literature review.

	Class of measure	Types of intervention and data sources
Broilers		
Tibial dischondroplasia	Prevention	Manipulation of nutrients (Edwards, 1990) Manipulation of feed consumption (Edwards and Sorensen, 1987; Onbasilar et al., 2007) Manipulation of egg incubation temp. (Yalcin et al., 2007)
Acites	Prevention	Feed restriction – full rearing period (Arce et al. 1992; Camacho-Fernandez et al., 2002; Rincon 2000) Feed restriction – early weeks (Acar et al., 1995; Arce et al., 1992; Khajali et al., 2007)
Clostridiosis	Treatment	Antibiotics (Tactacan et al., 2013; Zhang et al., 2010) Bacteriophage therapy (Miller et al., 2010) Other antimicrobials (Tactacan et al., 2013)
Coccidiosis	Prevention	Vaccines (Lee et al., 2009; Li et al., 2005; Miguel et al., 2008; Shirley et al., 1995; Sou et al., 2006; Vermeulen et al., 2001; Williams et al., 1999; Williams and Gobbi, 2002) Probiotics (Abdelrahman et al., 2014) Herbal treatments (Miguel et al., 2008) Anticoccidials (Abdelrahman et al., 2014; Lee et al., 2009; Li et al., 2005; Miguel et al., 2008; Sou et al., 2006; Williams et al., 1999; Williams and Gobbi, 2002)
Footpad dermatitis	Prevention	Manipulation of litter moisture (Cengiz et al., 2011; de Jong et al., 2014; Ekstrand et al., 1997; Martland, 1985; Mayne et al., 2007; Taira et al., 2013; Wang et al., 2010) Variation of litter materials (Bilgili et al., 2009)
Laying flocks		
Keel bone damage	Prevention	Switch from unenriched to enriched cages (Petrik et al., 2015; Sherwin et al., 2010; Wilkins et al., 2011)
Infectious bronchitis	Prevention	Vaccines (Cook et al., 1999; Faramarzi et al., 2014; Jones et al., 2005; Tarpey et al., 2006; Tawfik et al., 2013)
Salpingoperitonitis	Prevention	Probiotics (Shini et al., 2013) Inoculation (Reid and Bocking, 2003) Vaccination (Gregersen, et al., 2010)
	Treatment	Antimicrobials (Balevi et al., 2001; Nahashon et al., 1996; Willis and Read, 2008)
Injurious feather pecking	Prevention	Housing (Fossum et al., 2009) Beak trimming (Craig and Lee,1990) Enriched environment (El-Lethey et al., 2000; Lambton et al., 2013) Reduced stocking rates (Nicol et al., 1999) Feed modification (Ambrosen and Petersen,1997)

There are two possible explanations for the discrepancy between the results of the scientific trials and real-world experience. First, that the few studies available are simply generating unrepresentative results and, second, and perhaps more likely, that the reviewed studies are capturing sub-clinical disease impacts. Observation of commercial practice suggests that coccidiostats, such as ionophore antibiotics, while effective at controlling clinical disease, are seemingly less effective at controlling subclinical impacts, leading to losses through reduced feed intake and feed conversion efficiency (Christensen, 2016).

4. Discussion

Our study found that there is an almost complete absence of published studies generating data on the financial impacts of these nine poultry production diseases. Generalising from this, it might be supposed that the entire poultry disease literature has very much an epidemiological, rather than financial, focus.

To estimate the financial impacts of the nine poultry production diseases, and control interventions, it was necessary to apply data on changes to productive parameters to standard financial models (for broilers and layers) in order to monetise them. However, there are significant gaps, even in the data on the impacts of diseases on productive parameters, a case in point being salpingoperitonitis, where there are insufficient data to permit any estimation of financial impact. This is perhaps explicable in view of the tendency for salpingoperitonitis to occur in conjunction with other E. Coli-induced conditions, such as airsaculitis, and secondary infections such as septicemia.

There is great heterogeneity of research objectives and methodology in the reviewed studies, with some focusing on disease incidence, others on disease severity, others seeking to capture the physical impacts of the disease itself, while others are concerned only with the efficacy of control interventions. As a consequence of this, together with the few studies, there is little or no replication in the literature and, sometimes, essential data are only available from a single study. This limitation affects the level of confidence that can be placed in the available data when generalising to the whole sector.

The lack of focus on finanial impacts in studies means that, even if data on changes to productive parameters are available and can be monetised, impacts on some cost categories, such as vet and medicine costs, still cannot be captured. With very little data on the impact of production diseases on the quality of outputs, the full financial impact of downgrades to carcasses or eggs cannot be accounted for, and so disease impacts may be underestimated. The lack of data on the cost of interventions means that the estimates of the financial savings resulting from using them may be over-estimated in our study.

Different studies often show a wide range of severity of impacts for the same disease. More extreme impacts than estimated here might occur in commercial practice for a number of reasons, including variations in: rearing environment; breed; management quality; and the pathogenicity of infections. An additional cause of variation is the occurrence of secondary infections. Most studies do not report data where secondary infections are known to have occurred, on the grounds that such data would bias impact estimates for the individual production diseases themselves. However, it must be acknowledged that part of the set of negative consequences arising from the occurrence of production diseases is an elevated risk of secondary infections from other diseases.

For the reasons identified above, it is concluded that there are deficiencies in the literature (and in the underlying reported research) resulting in data which are difficult to use. Thus, the financial impacts estimated for the production diseases examined here should be treated with some caution. Despite this, the claims made by many authors in the poultry disease literature that production diseases can have significant financial impacts would appear correct, even though these authors seldom supply any empirical financial evidence supporting these claims.

While poultry farms with elevated levels of production diseases can make substantially less profit than farms with low disease levels, these losses can be significantly reduced by a range of prevention measures, such as vaccinations, or improved litter management, nutrition and hygiene, as well as curative treatments. The financial benefits of interventions to control production diseases vary greatly according to disease and the intervention chosen. The losses associated with diseases such as clostridiosis, for example, can be significantly reduced through use of antimicrobials, but others, such as keel bone damage, present a greater challenge.

The reliance of the poultry industry on the use of antimicrobials to control infectious diseases highlights the risks to the financial sustainability of the sector from the continuing growth in farm bacterial reservoirs with resistance to antimicrobial treatments (Aminov and Mackie, 2007; Sykes, 2010, EFSA and ECDPC, 2016).

These risks occur on three fronts. First, some antibiotics commonly used for the treatment of diseases may lose their efficacy. Second, government action plans, such as the EU Action Plan Against the Rising Threats from Antimicrobial Resistance (EU, 2011), which are designed to drive more responsible use of antibiotics, may make some antibiotics less readily available. Third, although there have been few official bans on the use of selected antibiotics so far, such as the US ban on Fluoroquinolones (FDA, 2005), governments may adopt the ’precautionary principle’, and issue complete bans on the use of some antibiotics.

5. Conclusions

In light of this growing threat, there is a pressing need for the poultry research community to help identify cost-effective alternatives to antibiotics which offer similar levels of disease control. These could include: novel substances to strengthen the poultry immune response to bacterial infection; naturally occurring bacteriophages; novel vaccinations; and enhanced biosecurity measures on farm. Although some rigorous individual studies of alternative approaches have been undertaken, there is insufficient data across the literature to evaluate them. Failure to develop these alternatives could significantly, and negatively, impact the future financial sustainability of the global poultry industry.

There are strong hints in the literature that some interventions, particularly in relation to biosecurity measures, reduce disease incidence, prevalence and severity, for multiple production diseases simultaneously. The use of single interventions to control multiple diseases would be very advantageous for an industry faced with small profit margins, volatile markets, and the possibility of further regulation. The industry would, therefore, benefit from a more holistic effort from the research community to identify the most useful and cost-effective multi-functional interventions to reduce disease-related financial losses.

The analysis above has revealed a disconnect between the requirements of the poultry industry for data on the financial impacts of diseases and control measures and the goals of researchers in the non-commercial poultry disease research community. As a consequence, the value of such research, even if it targets relevant production diseases and interventions, is of less value than it could be. In view of this, the question might reasonably be asked, where are commercial producers and their advisors getting the data on which to plan their disease management programmes?

In order to meet the future informational needs of the poultry industry, the focus of academic poultry disease research needs to be changed. Studies need to generate data not only on the first-order physical impacts of production diseases, but also secondary and financial impacts, as is currently already being achieved commonly in research on pig and dairy cow diseases. This means collecting data from abbatoirs on the impact of diseases on product quality, as well as data from farm trials and lab-based experiments on changes to the levels of input use resulting from diseases and the interventions to control them. This would require a more inter-disciplinary approach to research, involving not just veterinarians or animal scientists, but also agricultural economists.

Acknowledgement

The work on which this paper is based was made possible by funding from the EU's DG Research Framework 7 Programme PROHEALTH project http://www.fp7-prohealth.eu/

Conflict of interest

The authors know of no conflict of interest in relation to the production or publication of this article.

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Appendix A. Standard financial models for broiler and layer enterprises, 2013

	Broilers	Layers
Sales:	**Revenues (€/ 100 kg live weight)** [6]	**Revenues (€ / hen)** [6]
Broilers, (2.276 g of meat per bird at €107.7/100 kg liveweight); Layers, 340 eggs at €7.6/100 eggs [7]	107.7	25.84
Spent hens	-	0.36
Expenditure:	**Production costs (€/ 100 kg live weight)** [10]	**Production costs (€ / hen)** [8, 9]
Day old chicks / pullets (17 weeks)	15.20	3.30
Mortality[1]	2.02	0.87
Feed	67.00	10.29
Medication, [5]	1.40	0.09 [4]
Heating and electricity	2.20	1.41 [4]
Water	0.60	
Litter (incl. cleanout & disposal)	3.70	
Labour	3.40	1.10
Housing [2]	6.40	2.75
General [3]	1.00	0.41
Total costs	102.92	20.22
Net margin	**4.74**	**5.98**

[1] Mortality costs assumed to be 50% of total rearing costs per dead bird. Mortality rate for layers assumed to be 9%.

[2] Housing costs includes: poultry house and inventory.

[3] General costs include: insurance, office, consultancy, telephone, transport.

[4] Medication, heating and electricity, water and litter costs are equated with the 'Other variable costs' category of Van Horne (2014), which includes: heating, electricity, litter, animal health and catching.

[5] Medication costs for broilers taken from Cocsik et al. (2014); layers from RBR (2014).

[6] 2013 broiler meat and egg prices; Eurostat Median of EU28 prices (authors' own calculations) http://ec.europa.eu/eurostat/statistics-explained/index.php/Agricultural_accounts_and_prices

[7] Number of eggs produced per housed bird = 340 (source: van Horne, 2014), based on enriched cage system).

[8] Sources: Van Horne (2014); Agro-Business Consultants Ltd (2012); RBR (2014).

[9] 2013 prices (based on 2010 (Van Horne, 2014) prices adjusted for inflation using annual GDP deflators for the EU. Source: World Bank National Accounts Data & OECD National Accounts files 2010-2015)

[10] Sources: Van Horne (2014); Agro-Business Consultants Ltd (2012).