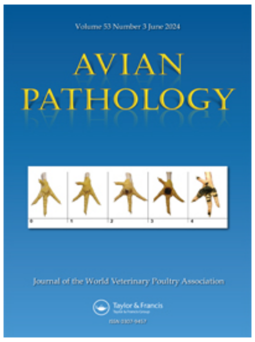

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ORIGINAL ARTICLE

The financial cost of coccidiosis in Algerian chicken production: a major challenge for the poultry sector

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ABSTRACT
Coccidiosis, caused by parasites of the genus *Eimeria*, is a significant economic burden to the poultry industry. In this study, we conducted a comprehensive analysis to evaluate the financial losses associated with *Eimeria* infection in chickens in Algeria, relying on data provided by key stakeholders in the Algerian poultry industry to assess sub-clinical as well as clinical impact. We employed the updated 2020 version of a model established to estimate the cost of coccidiosis in chickens, taking into consideration specific cultural and technical aspects of poultry farming in Algeria. The findings predict economic losses due to coccidiosis in chickens of approximately £86.7 million in Algeria for the year 2022, representing £0.30 per chicken raised. The majority of the cost was attributed to morbidity (74.9%), emphasizing the substantial economic impact of reduced productivity including decreased bodyweight gain and increased feed conversion ratio. Costs associated with control measures made up 20.5% of the total calculated cost, with 4.6% of the cost related to mortality. These figures provide a clear indication of the scope and economic impact of *Eimeria* infection of chickens in Algeria, illustrating the impact of practices common across North Africa. They underscore the ongoing requirement for effective preventive and control measures to reduce these financial losses while improving productivity and welfare, ensuring the economic sustainability of the Algerian poultry industry.

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Eimeria; coccidiosis; chickens; economic losses; cost; Algeria

Introduction

In Algeria, the poultry industry plays vital roles in the agricultural economy and meeting increasing demands for meat and eggs for human consumption (Bouzid *et al.*, 2022). As the global human population is predicted to exceed 9 billion by 2050 (O'Neill *et al.*, 2010), diseases of poultry have been reinforced as significant concerns for industry and food security. A key example is the global challenge of avian coccidiosis, caused by parasites of the genus *Eimeria*. *Eimeria* infection of chickens incurs substantial economic consequences, with the global cost estimated to exceed £10.3 billion in 2016 including production losses and expenses related to prevention and treatment (Blake *et al.*, 2020). *Eimeria* and the disease coccidiosis pose a substantial threat to food security, bird welfare, and the global agro-economy. Effectively managing and preventing this disease is essential to ensure sustainable poultry production and to meet the growing demand for inclusion of poultry products in human diets (Williams, 2005; Adhikari *et al.*, 2020).

The Algerian poultry industry faces a considerable challenge due to avian coccidiosis, with prevalence increasing in recent years (Rahmani *et al.*, 2021; Djemai *et al.*, 2022). *Eimeria* infection can undermine chicken productivity, with treatment and prevention costs for prophylactic drugs and vaccines combining to reduce profitability of poultry farms (Williams, 1998; Gilbert *et al.*, 2020), but the true financial cost has not been estimated for Algeria. Understanding the cost of coccidiosis in chickens in Algeria would inform on the direct and indirect costs associated with *Eimeria*, providing invaluable data to shape policies for disease prevention and management in the country and across much of North Africa. Improved awareness would empower stakeholders in the poultry industry to make informed decisions aimed at minimizing economic losses, maximizing bird welfare, and fostering sustainable poultry production.

To address this knowledge gap, this article applies the compartmentalised model developed by Williams to estimate the cost of coccidiosis in chickens (Williams, 1999) as updated for the year 2016 (Blake *et al.*, 2020) to empirically illustrate the economic challenges posed by coccidiosis of chickens in Algeria. This model defines a series of economic parameters

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that are affected by coccidiosis, including costs of mortality, morbidity, treatment, productivity losses, and expenses related to prophylactic control. Leveraging data collected in 2022 from key stakeholders in the poultry industry across different regions of Algeria, it accounts for recent changes and specificities in farming practices.

Materials and methods

Data collection and methodology

To evaluate the financial costs and losses associated with coccidiosis of chickens in the Algerian poultry industry we applied an updated compartmental model based upon a series of 12 interconnected components (Williams, 1999; Blake *et al*., 2020). Interpretation of the model has been modified to consider local poultry rearing practices, standard prophylactic and therapeutic protocols, and specific health and production parameters prevalent in Algerian poultry farms.

For data acquisition, a questionnaire was designed and subsequently validated by the Biosafety-Biosecurity Advisory Committee (BSS) of the Biotechnology Research Center (CRBt) in Algeria. The questionnaire, referenced as EPA-CRBt 2022-BSS-01, was systematically distributed to influential figures in the Algerian poultry industry while carefully preserving the anonymity of the respondents. In cases where data were presented as ranges, medians were calculated to enhance the precision and reliability of the results.

Poultry production statistics were accessed using the FAOSTAT database (http://www.fao.org/faostat/) for 2021, the latest available year, supplemented with poultry management references and interviews with industry representatives throughout 2022.

Data analysis and economic modelling

Four categories of poultry production were included in the model: broiler chickens reared for meat, broiler breeder chickens, layer chickens kept for eggs and layer breeder chickens, covered by 12 compartments (Table 1, Blake *et al*., 2020).

Prices, international currencies and quantity calculations

The analysis used nominal prices from 2022. The exchange rates used in this study were established using the Central Bank of Algeria as of September 30, 2022. The rate against one (1) British pound (sterling) was 169.08 Algerian dinars.

Results

In this study, we utilized the updated version of the Williams model (Blake *et al*., 2020) to estimate the economic costs and losses caused by coccidiosis of chickens in Algeria. To make these estimations more relevant to the Algerian context, we considered certain common practices and parameters specific to Algerian poultry farming. Costs were expressed in British pounds sterling (£) to better align with the country's economic reality.

The total cost of anticoccidial prophylaxis

Broilers and broiler breeders

In our research we referred to the Aviagen Broiler Management Manuals which indicated that approximately 74.3% of a broiler carcass weight could be utilized for meat. However, to maintain a cautious approach, we adopted a conservative estimate of

Table 1. Compartments and modifications for estimation of the financial cost of coccidiosis in Algerian chickens (Williams, 1999; Blake *et al*., 2020).

Cost category	Cost Type	Amended	Edit
1. Broiler chicken prophylaxis	Control	Yes*	Vaccination excluded, % using medication prophylaxis, cost
2. Broiler breeder chicken prophylaxis	Control	Yes*	% of broiler breeder chickens raised with chemoprophylaxis, cost (chemical, ionophores), quantity of feed consumed, % using medication prophylaxis, cost
3. Layer chicken prophylaxis	Control	Yes*	Vaccination excluded, % of layer chickens raised with chemoprophylaxis, cost (chemical, ionophores), quantity of feed consumed, % using medication prophylaxis, cost
4. Layer-breeder chicken prophylaxis	Control	Yes*	% of layer-breeders raised with chemoprophylaxis, cost (chemical, ionophores), quantity of feed consumed, % using medication prophylaxis, cost
5. Broiler chicken anticoccidial therapy	Control	No	-
6. Broiler breeder chicken anticoccidial therapy	Control	No	-
7. Layer chicken anticoccidial therapy	Control	No	-
8. Layer breeder chicken anticoccidial therapy	Control	No	-
9. Lost broiler chicken weight gain	Morbidity	No	-
10. Increased feed conversion Ratio (FCR)	Morbidity	No	-
11. Loss of egg production	Morbidity	Yes*	% clinical and sub-clinical coccidiosis in layer chickens (cost of consumption eggs)
12. Broiler chicken mortality	Mortality	No	-

* These adjustments were implemented to consider the unique aspects and variations in poultry farming practices in Algeria as compared to the original model (Williams, 1999; Blake *et al*., 2020).

Table 2. Values used to calculate the cost of anticoccidial prophylaxis in Algerian broiler and broiler breeder chickens.

Parameter	Value
1. Values used to calculate the cost of prophylaxis in broiler chickens	
Number of broilers slaughtered for meat per year (millions)	258
Tonnes produced, live weight	0.75
Tonnes dressed meat (millions)	0.53
% carcass used	71
FCR	1.9
% formulated feed (i.e. not wheat/cereal)	100
% starter	18
% grower	54.5
% finisher (inc. drugs withdrawal)	27.5
Cost chemical/combination drug per tonne food	£11.24
Cost ionophore drug per tonne food	£8.28
% broilers reared on drugs	100
% broilers reared on drugs in starter feed	40.15
% broilers reared on drugs in grower feed	52.27
% broilers reared on drugs in finisher feed	7.57
Vaccine (broiler) pence per dose	£0.20
% broilers reared with vaccine	0
Mean finishing weight broiler (Kg)	2.9
% of applied drug prophylaxis practices	75
Cost of drug prophylaxis per 1000 chickens	£38.44
2. Values used to calculate the cost of prophylaxis in broiler breeders	
% broiler breeders in population (0.77%) million	1.98
Vaccine (breeder) pence per dose	£0.20
% broiler breeders reared with vaccine	100
Feed consumption of broiler breeder chickens for the starter phase (0-4 weeks) (kg)	3
Cost ionophores/combination drug per tonne food	£11.24
% broiler breeder chickens reared on drugs in the starter phase (0-4 weeks) feed	92.5
Feed consumption of broiler breeder chickens for the grower phase (4-16 weeks) (kg)	10
Cost ionophores/combination drug per tonne food	£8.28
% broiler breeder chickens reared on drugs in the grower phase (4-16 weeks) feed	7.5
The medication prevention cost per broiler breeder chicken	£0.10
% of applied medication prevention in broiler breeder chickens	71%

71% of the total broiler carcass weight as described previously (Blake *et al.*, 2020), in line with the data supplied in our industry survey. Consequently, we calculated the quantity of dressed meat produced to be approximately 0.53 million tonnes (Equations 1 and 2). This estimation was based on a total broiler live weight production of 0.75 million tonnes in 2022 (Table 2).

$$\text{Meat yield factor} = \frac{100}{\%\ \text{carcass used}} \tag{1}$$

$$\text{Tonnes liveweight} = \text{Tonnes dressed meat} \times \text{Meat yield factor} \tag{2}$$

The data collected revealed that prophylaxis of broiler chickens in Algeria relied on administration of ionophore and chemical anticoccidial drugs. Anticoccidial vaccination is not currently practiced within the Algerian broiler sector, aligning with the situation reported in the UK in 1995, but not 2016 (Williams, 1999; Blake *et al.*, 2020).

Our data indicated that the average Feed Conversion Ratio (FCR) for broilers in Algeria stood at 1.9 in 2022. Notably, our findings suggested that the entire broiler diet in Algeria is comprised of corn and soy in formulated feed. Thus, if 0.75 million tonnes of live weight chickens were produced, the total quantity of feed consumed would have been 1.42 million tonnes (Equation 3).

$$\text{Feed consumtion} = \text{Tonnes liveweight} \times \text{FCR} \tag{3}$$

The data suggested that approximately 18% of the total diet would have been provided as starter feed during the initial days of a 47-day programme for chicks in production practices prevalent in Algeria. Consequently, out of the 1.42 million tonnes of formulated feed used, an estimated 0.25 million tonnes would have been allocated for consumption as starter feed. In the starter feed, a combination of chemical with or without ionophore drugs was utilized, with an average drug cost of £11.24 per tonne of supplemented feed. As a result, the total expenditure for chemoprophylaxis in broiler production would have been approximately £1.12 million. Throughout the grower phase approximately 54.5% of feed was consumed, amounting to 0.76 million tonnes and representing approximately £3.27 million for drug supplementation.

Chickens in the finishing phase received approximately 27.5% of the formulated feed consumed. Ionophores were usually employed alone during this stage, incurring an average expenditure of £8.28 per tonne of supplemented feed. Withdrawal periods varied depending on the choice of drug included in the finisher diet, but were approximately 25% of the finishing phase. Combined, this indicated a cost of drug supplementation during finishing of £0.17 million in 2022. Thus, the comprehensive estimated cost of anticoccidial feed supplementation reached £4.56 million for broilers.

In practice, the prevention of coccidiosis hinges on a combination of chemoprophylaxis with therapeutic interventions. In Algeria, the latter routinely entails the preventive administration of drugs such as sulfonamides, amprolium, toltrazuril, etc., to 18-day-old chicks for 2 to 3 days, incorporating these drugs into the drinking water. Approximately 75% of broiler chickens raised in Algeria in 2022 received these anticoccidial drugs through their drinking water, constituting 193.5 million chickens. The estimated cost of this drug prophylaxis for a batch of 1000 chickens amounts to £38.44 (Table 2). Consequently, the overall cost of coccidiosis drug prophylaxis, which encompasses the utilization of anticoccidial drugs, is projected to have been approximately £7.43 million in 2022 (Table 4).

In Algeria, all broiler breeders undergo systematic anticoccidial vaccination. Given the low percentage of broiler breeders employed for commercial broiler production, which stands at 0.77%, roughly 130 chicks are produced per broiler breeder hen (Blake *et al.*, 2020). Based on this data, it is estimated that approximately 1.98 million breeder chickens would have been

Table 3. Values used to calculate the cost of anticoccidial prophylaxis in broiler and laying hen breeding stock.

Parameter	Value
3. Values used to calculate the cost of prophylaxis in replacement layers	
Number layer chickens (millions)	24
% reared in cages	100
Vaccine (layer) pence per dose	£0.20
Feed consumed of the ring step-down (kg, weeks 0–3)	0.4
Feed consumed of the ring step-down (kg, weeks 4–6)	0.71
Feed consumed of the ring step-down (kg, weeks 7–12)	2.22
% reared fed drugs	100
% reared vaccinated	0
Cost ionophores drug per tonne food	£8.28
% applied medication prevention	70
The medication prevention cost per replacement layer chicken	£0.10
4. Values used to calculate the cost of prophylaxis in layer breeders	
% layer flock as breeders	1.21
Vaccine (breeder) pence per dose	£0.20
Cost ionophores drug per tonne food	£8.28
Cost prophylactic medication per layer breeder	£0.09
% layer breeders on drugs per tonne food	20
% layer breeders vaccinated	80
% applied medication prevention	70

required to achieve the production of 258 million broiler chickens in Algeria in 2022. The average cost of anticoccidial vaccination per broiler breeder in Algeria for 2022 was approximately £0.20, resulting in a total annual cost of roughly £0.4 million (Table 4).

In Algeria, broiler breeders are typically provided with a specific diet, often supplemented with anticoccidial medications, in addition to vaccination. The poultry industry adopts this strategy to maximize preventive measures and optimize chicken productivity. Although this approach may seem contradictory, it remains common in the Algerian poultry sector. According to the Aviagen broiler management manuals, it has been established that each chicken consumes approximately 3 kg of feed during the starter phase (0–4 weeks), whereas more than 10 kg of feed is consumed during the growth phase (4–16 weeks). Based on the survey results, it was observed that anticoccidials (chemical or ionophores) are included in feed at a rate of 92.5% during the starter phase and 7.5% during the growth phase (Table 2). Therefore, the total estimated cost of anticoccidial supplementation in feed was £0.07 million for broiler breeders that received chemoprophylaxis.

Further, around 71% of broiler breeders use drugs as a scheduled prophylactic intervention, administering these anticoccidial drugs in the drinking water, at a cost of £0.10 per chicken. This translates into an estimated total cost of £0.14 million. The total cost of coccidiosis prophylaxis in the broiler breeder poultry industry in Algeria amounts to £0.6 million in 2022 (Table 4).

Layer and layer breeder chickens

FAOSTAT data indicate that Algeria has a total of 24 million laying hens. In Williams' initial model, vaccination was not considered for anticoccidial prophylaxis of laying hens, with 100% chemoprophylaxis used (Williams, 1999). This approach is similar to that adopted by layer breeders in Algeria, where survey data confirm that the rearing of laying hens in cages is predominant and that they rely mainly on chemoprophylaxis with scheduled therapeutic intervention to prevent coccidiosis infections and maintain the health and productivity of laying hens.

In accordance with laying hen management guidelines, specific feed intake recommendations have been established for each phase within the three-stage system spanning from 0–3 weeks, 4–6 weeks, and extending from 7–12 weeks (Table 3 and Blake *et al.*, 2020). During the initial phase (0–3 weeks), it is expected that laying hens consume approximately 0.40 kg of feed per bird. As they progress into the subsequent phase (4–6 weeks) this intake rate increases to approximately 0.71 kg per bird. In the final phase (7–12 weeks), feed consumption is estimated to be 2.22 kg per bird.

Regarding coccidial chemoprophylaxis, use of ionophores is most common for caged laying hens in Algeria. The associated cost linked to ionophore supplementation is estimated at £8.28 per tonne of feed. Consequently, when one takes into account these meticulously defined dietary guidelines and factors in the cost of ionophore supplementation, the total financial allocation for coccidial chemoprophylaxis in laying hens is projected to amount to approximately £0.66 million.

Again, scheduled drug therapy was practiced by 70% of layer chicken farmers in Algeria, incurring an estimated cost of £0.10 per chicken. Consequently, the aggregate cost associated with this form of prophylaxis was approximately £1.51 million. When we amalgamate the costs of these two distinct drug-based approaches, namely chemoprophylaxis and the scheduled application of therapeutic drugs, the cumulative financial outlay was a total of £2.17 million in the fiscal year 2022 (Tables 4 and 9).

Table 4. A comparison of costs for drug- and vaccine-based control of coccidiosis in Algeria.

Economic parameter	Chicken production system					
	Broiler	Broiler breeder	Replacement layers	Layer breeder	Total	%
Total cost of vaccination (millions)	£0.00	£0.40	£0.00	£0.046	£0.44	2.97
Total cost of chemoprophylaxis (millions)	£4.56	£0.07	£0.66	£0.0016	£5.29	35.74
Total cost of prophylactic medication (millions)	£7.43	£0.14	£1.51	£0.02	£9.10	61.48
Total	£11.99	£0.60	£2.17	£0.067	£14.80	
%	81.01	4.05	14.66	0.45		

Drawing on data from Williams (1999), which presupposes a consistent ratio of 1.21% between layer breeders to commercial layer progeny (Table 3), approximately 290,400 chicks would have been raised to sustain the reproduction of laying hens in Algeria during the year 2022. Furthermore, when factoring in that 80% of laying hen breeding stock receive anticoccidial vaccination, incurring an estimated average cost of £0.20 per individual, the overall annual expense for vaccinating laying breeders would have been £0.046 million (Table 4). The remaining 20% of laying hen breeders receive chemoprophylaxis administered through their feed. Employing cost estimates for chemoprophylaxis analogous to those for laying hens (Table 3), the cumulative annual cost of chemoprophylaxis is projected to be £0.0016 million.

Recognising that 70% of layer breeder farmers also administer medicinal prophylaxis as a preventive measure against coccidiosis at an average cost of £0.10 per chicken, an additional cost of £0.02 million would have been incurred.

The total cost of anticoccidial therapy

Our investigation yielded varying rates of coccidiosis incidence across different poultry categories in Algeria. Specifically, we found the following incidence rates: 17.5% for broiler flocks, 27.5% for broiler breeders, and 10% for layers and layer breeders, as presented in Table 5. Based on these data, we calculated therapeutic treatment costs, estimating £0.06 per broiler chicken and £0.16 for other poultry categories. When extrapolating these findings to the year 2022, we determined that approximately 43.86 million broiler chickens, 534,600 broiler breeders, 2.4 million layers, and 29,040 layer breeders required coccidiosis treatment in Algeria.

Using Equation (4), it becomes evident that broilers bear the largest economic burden, totalling £2.5 million, which represents 85.9% of the total cost. Layers account for the second-highest cost, at 12.8% of the overall expenditure, equivalent to £0.38 million. Broiler breeders and layer breeders, on the other hand, have respective estimated costs of £0.085 million and £0.0046 million (Table 6).

Table 5. Values used to calculate the cost of anticoccidial therapy in four types of chicken production systems.

Parameter	Value
5. Values used to calculate the cost of anticoccidial therapy in broiler chickens	
% flocks affected by coccidiosis	17.5
Cost of treatment per bird	£0.06
6. Values used to calculate the cost of anticoccidial therapy in broiler breeder chickens	
% flocks affected by coccidiosis	27.5
Pence treatment per bird	£0.16
7. Values used to calculate the cost of anticoccidial therapy in replacement layers	
% flocks affected by coccidiosis	10
Cost of treatment per bird	£0.16
8. Values used to calculate the cost of anticoccidial therapy in layer breeders	
% flocks affected by coccidiosis	10
Cost of treatment per bird	£0.16

Table 6. A comparison of the total cost of anticoccidial therapy between different chicken productions systems in Algeria.

	Chicken production system				
Economic parameter	Broiler	Broiler breeder	Layer	Layer breeder	Total
Total cost of therapy (millions)	£2.5	£0.085	£0.38	£0.0046	£2.97
Percentage	85.9	2.86	12.8	0.15	

$$\begin{aligned}\text{Cost of Therapy} =& \\ &\text{Number of chickens} \\ &\times\ \text{\% occurence of coccidiosis} \\ &\times\ \text{cost of treatment}\end{aligned} \tag{4}$$

The cost of morbidity: reduced broiler weight gains due to coccidiosis

While *Eimeria* infection can affect all poultry species at various stages of their life cycles, its most prevalent impact is characterized by enteritis, disrupting nutrient absorption and subsequently leading to impaired weight gain (Chapman & Jeffers, 2014).

In the original model, the anticipated reduction in final bodyweight due to coccidiosis stood at an average of 0.1 kg in comparison to an unexposed group. However, to exercise a conservative estimate, a more cautious estimate of 0.05 kg was employed (Williams, 1999). Recent research focusing on *Eimeria* species known to induce malabsorption issues, notably *E. acervulina* and *E. maxima*, indicates an even more substantial impact, with weight reductions surpassing 0.1 kg (Blake *et al.*, 2020). Considering this information, coupled with the trend for modern broiler lines to exhibit accelerated growth, suggests a potentially more pronounced effect of *Eimeria* infection on their bodyweight. Hence, we embraced Blake's methodology, which adopted a conservative estimate of a final live weight reduction of 0.07 kg following *Eimeria* infection (Table 7).

According to our calculations, considering the production of 258 million broilers in Algeria for the year 2022, *Eimeria* infection would lead to a collective reduction in bodyweight totalling 19,950,000 kg. Applying the previously mentioned value of £1.59 per kg of bodyweight at the time of slaughter (Table 7), this cumulative loss would amount to £28.71 million in total (Equation 5).

$$\begin{aligned}&\text{Cost of reduced weight gain} \\ &\quad = \{\text{Number of chickens} \times \text{Predicted weight loss (kg)}\} \\ &\quad \times\ \text{£ per kg at slaughter}\end{aligned} \tag{5}$$

Table 7. Values used to calculate performance costs of coccidiosis in broiler, layer and broiler breeder chickens.

Parameter	Value
9. Cost of reduced weight due to coccidiosis	
Average broiler weight loss due to coccidiosis (kg)	0.1
Conservative prediction of weight loss (kg)	0.07
Value loss per Kg (selling price per kg)	£1.59
10. Cost of increased FCR	
Increased FCR as a consequence of coccidiosis	0.1
Conservative estimate FCR increase	0.05
Mean formulated feed price per tonne	£520
Mean wheat (or other cereal) price per tonne	£354
% formulated feed (i.e. not wheat/cereal)	100
11. Cost reduced egg production	
% broiler breeders that were parent hens	90.9
% broiler egg hatchability	85
Cost 1-day-old broiler chick	£0.41
Number layer chickens (millions)	24
% flocks affected by coccidiosis	10%
Average egg laying rate	85%
% decrease in laying	30
Duration of harmful effects of *Eimeria* on laying (days)	31
Number of lost eggs for consumption	18
Total cost of table eggs	£0.088
12. Cost of broiler mortality due to coccidiosis	
% mortality due to coccidiosis	2.75
Value, including chick costs, at 3 weeks	£1.30
Av. liveweight at slaughter (kg)	2.9
Av. slaughter price/kg	£1.59
Cost of rearing bird to final weight (no chick costs)	£2.70

Table 8. A comparison of loss between chickens reared in different production systems and performance cost due to coccidiosis in Algeria.

Economic parameter	Chicken production system			
	Broiler	Broiler breeders	Replacement layers	Total (millions)
Total cost of reduced weight gain (millions)	£36.92	–	–	
Total cost of increased FCR (millions)	£27.30	–	–	
Cost of lower broiler breeder egg production (millions)	–	£0.17	–	
Cost of lower replacement layers egg production (millions)	–	–	£0.48	
Total cost of broiler mortality (millions)	£4.00	–	–	
Total (millions)	£68.22	£0.17	£0.48	£68.87
Percentage	99.05	0.24	0.70	

Modifying the estimate of liveweight reduction by ±0.02 kg had a considerable impact on the overall cost, leading to a variation of 28.6%. The estimated costs ranged from £20.49 million to £36.92 million. This underscores the detrimental influence of coccidiosis on chicken performance, particularly within the context of the average, or even subpar, breeding conditions observed in Algeria. Such conditions have a markedly adverse effect on chicken performance, resulting in a substantial increase in the total cost to £36.92 million (Table 8).

The cost of morbidity: increased feed conversion ratios (FCR) due to coccidiosis

In addition to the observable reduction in final body weight, *Eimeria* infection in broilers significantly diminishes nutrient absorption, thereby leading to an elevated feed conversion ratio (FCR) (Gilbert *et al.*, 2020). In the original model developed by Williams, the impact of *Eimeria* infection on feed conversion ratio (FCR) was estimated to result in an increase of 0.1, with a conservative estimate of 0.05 (Williams, 1999). These estimations were also adopted in our study (Table 7). Our data revealed that broiler diets in Algeria are exclusively formulated with 100% corn-soy, with an average cost of £520 per tonne (Table 7). Using the annual liveweight figures for broilers, as previously mentioned, we calculated the additional costs attributed to the heightened FCR due to coccidiosis infection, amounting to £19.50 million (Equation 6).

$$\begin{aligned}\text{Cost of increased FCR} \ = \\ &(\text{Broiler liveweight produced kg},\\ &(\text{from Equation 2})\\ &\times \text{ Predicted FCR increase})\\ &\times \text{Average total feed cost} \qquad (6)\end{aligned}$$

Adjusting the estimated increase in FCR by ±0.02 kg had a significant impact on the total cost, leading to a variation of 40%. The range of values shifted between £11.7 million and £27.3 million. As above, this highlights the detrimental impact of coccidiosis on chicken performance, especially in countries such as Algeria where suboptimal conditions are common. These conditions significantly impair chicken performance, resulting in a substantial elevation of FCR and total costs, potentially reaching as high as £27.3 million (Table 8).

The cost of morbidity: reduced egg production in broiler breeders and replacement layers

Numerous research studies have provided compelling evidence that *Eimeria* infection in laying hens can disrupt the absorption of vital nutrients essential for egg production. These nutrients include amino acids, carbohydrates, and calcium (Turk, 1978). The work of Chapman (2017) further emphasizes that the detrimental effects of *Eimeria* infection on egg production can persist for a period of 3–6 weeks, resulting in reductions in production ranging from 10% to 50%. It is important to note that the original Williams model from 1999 did not account for this factor.

To evaluate the economic implications of this scenario, we made the assumption that the detrimental effects of *Eimeria* infection on egg production persist for a duration of 4.5 weeks (equivalent to 31 days). During this time, we estimated a 30% reduction in production. Based on these assumptions and considering a clinical coccidiosis incidence of 10%, we can estimate that approximately 0.24 million laying hens would be affected (Table 7).

When we consider the projected loss of 18 eggs per affected laying hen (Equation 7) and apply an average value of £0.088 per egg (Table 7), the cumulative cost of table eggs lost due to *Eimeria* infection in laying hens would amount to £0.38 million in Algeria. This figure illustrates the substantial economic consequences of decreased egg production resulting from *Eimeria* infection in laying hens.

$$\begin{aligned}\text{Number of consumption eggs lost}\\ &= (31\text{ days } \times \text{ average \% laying})\\ &- (31\text{ days } \times \text{average laying rate}\\ &\times\text{\% reduction in production})\end{aligned} \tag{7}$$

In the case of the sub-clinical form of the disease, it can be approximated that at least one egg per chicken is lost due to *Eimeria* (Chapman, 2017). Our research findings indicate that approximately 50% of laying hens experience the sub-clinical form of infection. Consequently, a substantial quantity of eggs is impacted by *Eimeria*, resulting in reduced egg production. When factoring in a value of £0.088 per egg, the overall cost of table eggs lost due to sub-clinical coccidiosis is estimated at £0.1 million. Taking into account both the clinical and sub-clinical forms of coccidiosis in laying hens, the total estimated cost attributed to reduced egg production amounts to £0.48 million (Table 8).

In 2022, it was projected that 540,000 broiler breeder chickens in Algeria would be affected by coccidiosis. Among these, 490,000 were expected to be hens, considering a sex ratio of one male to 10 females in modern broiler breeders. However, the exact impact of *Eimeria* infection on egg production in broiler breeders is not conclusively defined (Blake *et al.*, 2020). Williams' model took a conservative stance, suggesting a loss of one egg per hen per year due to *Eimeria* infection. Nonetheless, the original model did not incorporate the egg hatching parameter. It has been observed that only 85% of eggs successfully hatch and produce chicks (Abucābos, 2010). According to our survey, the average cost of a day-old broiler chick was £0.41. This implies a total loss of £0.17 million attributed to reduced egg production among broiler breeder hens affected by *Eimeria* infection (Tables 7 and 8).

The cost of broiler mortality caused by coccidiosis

Our survey results indicated that roughly 2.7% of broiler chickens in Algeria either die or need to be slaughtered because of coccidiosis within poultry houses when the disease is present (Table 7). Considering there were approximately 43.86 million broilers in such facilities, this results in an estimated mortality of about 1.24 million chickens (Equation 8).

$$\begin{aligned}&\text{Mortality due to coccidiosis}\\ &= \text{Number chickens affected by coccidiosis}\\ &\quad\times\text{\% mortality}\end{aligned} \tag{8}$$

In the Williams model, we assessed losses linked to chicken mortality by considering the economic value of each chicken. This included their initial acquisition costs and the income lost from unsellable chickens. We also factor in the savings from reduced breeding expenses due to early mortality (Equation 10) (Williams, 1999). Our calculation of chicken value was based on a 3-week timeframe, as this is when mortality is most prevalent.

Based on our survey data, the average price of a 3-week-old broiler chicken was estimated to be £1.30, resulting in an overall cost of £1.61 million (Equation 9). In 2022, the average liveweight of a commercial broiler chicken in Algeria at the time of slaughter was approximately 2.9 kg.

Our survey also found that at the time of slaughter, the average price per kg of broiler chicken was £1.59. Consequently, the loss incurred due to mortality amounts to £4.61 per chicken. However, this loss is partially mitigated by a reduction in breeding expenses of £2.70 per deceased chicken. This results in a net loss of £1.91 per chicken, which aggregates to a total of £2.39 million (Equation 10). Consequently, the comprehensive cost of broiler mortality in Algeria for the year 2022 stands at £4 million.

$$\begin{aligned}&\text{Value of chickens lost due to coccidiosis}\\ &= \text{Chicken mortality}\\ &\quad\times\text{ Estimated value at 3 weeks}\end{aligned} \tag{9}$$

$$\begin{aligned}\text{Net loss} = &[(\text{Number dead} \times \text{Av. liveweight at slaughter})\\ &\times \text{£ per kg at slaughter}] - (\text{Number dead}\\ &\times \text{Cost of rearing to final weight from 3 weeks})\end{aligned} \tag{10}$$

It is worth highlighting that in Williams' original model the computation of mortality costs for other chicken categories was omitted. This omission primarily stemmed from the difficulties in accurately estimating these costs and the intricacies involved in determining category-specific expenses (Blake *et al.*, 2020).

The financial cost of coccidiosis in chickens in Algeria

Estimations of the financial consequences of coccidiosis in chickens can exhibit substantial variations. These disparities are influenced by several factors, including the prevalence of the infection, the size of the poultry industry, the specific categories of chickens affected, the strategies employed for prevention and treatment, and the economic variables specific to each country.

In an effort to increase precision, we opted for an updated version of the Williams model as established in 2020 (Blake *et al*., 2020) to calculate the total cost of coccidiosis in chickens in Algeria. This updated version takes into account the most recent data regarding consumer preferences, market conditions, breeding environments, and region-specific biosecurity measures. Based on this updated information for the year 2022, our estimate of the total financial cost of coccidiosis is £70.63 million per year in Algeria. These figures highlight the considerable economic impact of the disease on the country's poultry industry.

It is crucial to acknowledge that regional disparities may exist and impact these findings. Thus, it is advisable to fine-tune these estimates according to particular local circumstances. The intricacies of coccidiosis in our context stem from a multitude of factors, primarily encompassing variation in poultry farm biosecurity, elevated disease prevalence, drug resistance issues, substantial prevention and treatment expenses, and diminished productivity.

In the specific Algerian context, we proposed constraining the supplementary influence of coccidiosis on weight gain reduction and FCR increment to +0.02. This pragmatic approach has had a notable effect, resulting in a 22.5% escalation in the overall cost, reaching £86.66 million.

Table 9 presents a comprehensive breakdown of the cost associated with coccidiosis across various poultry categories, offering a crucial insight into the economic repercussions of this disease within the Algerian poultry sector in 2022. A horizontal examination of the data reveals that broilers shoulder the most substantial financial burden, incurring total costs of £82.71 million, constituting the majority, or 95.44%, of the overall expenses. Conversely, broiler breeders, layers, and layer breeders face relatively lower costs, accounting for 0.98%, 3.49%, and 0.08% of the total expenses, respectively.

When we analyse the costs vertically, focusing on the different cost types, we can pinpoint the primary components. Prophylactic expenses related to coccidiosis prevention amount to £14.82 million, constituting 17.1% of the total expenditure. Therapeutic costs, encompassing treatments for the disease, reach £2.97 million, equivalent to 3.4% of the total expenses. The morbidity cost, reflecting the expenses associated with illness that does not lead to mortality, is substantial, particularly for broilers, at £64.22 million. Lastly, the cost attributed to broiler mortality resulting from coccidiosis-induced deaths totals £4 million. Thus, this analysis demonstrates that coccidiosis exerts a substantial economic burden, especially on broilers, primarily driven by the substantial costs linked to morbidity. Prophylactic and therapeutic expenses equally hold a pivotal role in addressing this disease.

Discussion

The significant impact of avian coccidiosis on the poultry industry has been well documented and the disease remains the primary parasitic challenge to poultry production (Blake & Tomley, 2014; Kadykalo *et al*., 2018). Coccidiosis has been classified as a "production disease", with impact from sub-clinical as well as clinical manifestations (Blake *et al*., 2021), but assessment of the economic impact of coccidiosis requires studies to be conducted in each country or region to account for local practices (Kinung'hi *et al*., 2004; Bera *et al*., 2010; Györke *et al*., 2016). Figures calculated to estimate the "overall cost" of coccidiosis in chickens have been widely cited, showing considerable variation (Allen & Fetterer, 2002; Dalloul & Lillehoj, 2006). Most recently, a study conducted for 2016 evaluated the financial costs of coccidiosis in eight key countries across six continents. This study confirmed that coccidiosis represents a considerable financial burden for global poultry production, resulting in estimated total losses of around £10.36 billion per annum (Blake *et al*., 2020).

Regional studies to assess the economic impact of coccidiosis have been scarce, with examples from Ethiopia and Romania (Kinung'hi *et al*., 2004; Györke *et al*., 2016). Costs per farm ranged from 898.80 to 5301.80 Ethiopian Birr per farm, and from 0.55 to 0.53 Birr per chicken in small and large Ethiopian farms, respectively. In Romania, flock costs were assessed at €3162.40 in 2010. A study in Ghana, Tanzania, and Zambia examined the impact of the presence of individual *Eimeria* species on the viability of small broiler farms, calculating gross economic

Table 9. The contribution of control costs, mortality and morbidity to the cost of coccidiosis by category of poultry (millions).

	Broiler	Broiler breeders	Replacement layers	Layers breeders	Total (millions)	Percentage
Total cost of prophylactic (millions)	£11.99	£0.60	£2.17	£0.067	£14.82	17.10
Total cost of therapy (millions)	£2.5	£0.085	£0.38	£0.0046	£2.97	3.42
Total cost of morbidity (millions)	£64.22	£0.17	£0.48	–	£64.87	74.85
Total cost of broiler mortality (millions)	£4.00	–	–	–	£4.00	4.61
Total (millions)	£82.71	£0.85	£3.03	£0.071	**£86.66**	
Percentage	95.44	0.98	3.49	0.08		

margins and identifying reductions associated with the presence of the more pathogenic species (Fornace *et al.*, 2013). Similarly, a study in Norway assessed the impact of sub-clinical *Eimeria* infection, identifying a significant impact without discussing the associated costs (Haug *et al.*, 2008).

Comparison of estimates for the cost of coccidiosis in chickens indicates a notable increase over time, primarily explained by growth in the number of chickens reared and monetary inflation, as demonstrated by Blake *et al.* (2020). Costs associated with broiler chicken prophylaxis and the impacts of *Eimeria* on growth have experienced a significant rise. This increase can be attributed in part to the considerable genetic advancements made by leading poultry breeding companies, selecting for broiler stocks with faster and more feed-efficient growth and therefore greater per bird impact of disease (Dierick *et al.*, 2019). Resistance to anticoccidial drugs can also inflate the costs of coccidiosis. Total resistance, for example to chemical coccidiostats such as diclazuril and nicarbazin, can result in the occurrence of clinical disease (Peek & Landman, 2011; Kadykalo *et al.*, 2018). Incomplete resistance (reduced efficacy) is more common, failing to effectively inhibit the activity of coccidia and compromising intestinal integrity, resulting in malabsorption, enteritis, reduced bodyweight gain (BWG) and increased FCR (Macdonald *et al.*, 2017; Macdonald *et al.*, 2019). Thus, understanding the overall financial cost of coccidiosis is crucial to the poultry industry. By assessing the actual economic impact of this disease, providing a baseline to compare farming systems, risk factors, and interventions (Rushton *et al.*, 2018), industry stakeholders can make informed decisions regarding investments required for prevention and control (Williams, 1999; Blake *et al.*, 2020). The effectiveness of coccidiosis prevention is closely tied to the adopted programme; well-designed and organized programmes play a crucial role in identifying and implementing necessary measures to reduce health risks and promote safety (Chapman & Jeffers, 2014; Chapman, 2017, 2018). Suitable preventive approaches not only limit economic losses but also foster more sustainable poultry practices (Kadykalo *et al.*, 2018).

To contextualize the cost of coccidiosis to the poultry sector in Algeria we initiated an assessment using an economic model developed by Williams (1999) as updated for the year 2016 (Blake *et al.*, 2020). Using costs and production data for the year 2022 revealed a financial cost of £86.66 million for coccidiosis in Algeria. The broiler sector accounted for nearly 95% of the overall financial losses, including prophylactic and therapeutic expenses, as well as costs related to reduced productivity, decreased BWG and increased FCR. Based on the number of slaughtered chickens and the calculated total cost, the average cost of coccidiosis per chicken produced in Algeria was high, almost double (£0.30) compared to the global average estimated for 2016 (£0.16) (Blake *et al.*, 2020).

Coccidiosis control measures are primarily preventive, commonly relying on the use of anticoccidial additives in chicken feed (Shivaramaiah *et al.*, 2014; Kadykalo *et al.*, 2018). In Algeria, coccidiosis prevention programmes rely heavily on routine chemoprophylaxis supplemented by the use of preventive drugs (i.e. scheduled therapeutic interventions). This approach is motivated by the lack of alternatives and aims to safeguard the economic feasibility of the poultry industry, but results in unusually high drug use increasing selection for drug resistance and the risk of residues in poultry products (Abbas *et al.*, 2011; Kadykalo *et al.*, 2018). Anticoccidial vaccination is not commonly practiced in Algerian poultry farming due to the high cost of vaccines compared to drugs, limited familiarity with vaccination, and national regulatory constraints that may apply to certain products. This situation is similar to that described in the study by Williams (1999). In Algeria in 2022 the cost of anticoccidial prophylaxis included £5.29 million and £9.17 million for dietary chemoprophylaxis and scheduled therapeutic interventions, respectively. Combined, these represented 97.05% of the total expenditure on anticoccidial prophylaxis and approximately 20.35% of the total financial expenses related to coccidiosis. In contrast, vaccination received only a modest resource allocation, accounting for just 2.95% of the coccidiosis prevention budget. Vaccination expenses were primarily attributed to broiler breeder and layer breeder stocks.

Morbidity made the major contribution to the cost of coccidiosis in Algerian chicken production, amounting to £64.87 million in 2022 (74.85% of the total cost). Incomplete control of *Eimeria* challenge results in reduced BWG, increased FCR, and decreased egg production. These findings align with previous studies, emphasizing the global extent of morbidity-related losses (Blake *et al.*, 2020). Detailed analysis of our survey demonstrated that the decrease in BWG contributed 42.60% (£36.92 million) of the total loss, while the increase in FCR represented 31.50% (£27.30 million). In India, losses related to increased FCR have been estimated to represent 23.74% of the total cost (Bera *et al.*, 2010). More recently, lost BWG attributed to *Eimeria* infection was estimated to represent 23–75% of the cost of coccidiosis in Brazil, Egypt, Guatemala, India, New Zealand, Nigeria, the UK and the USA, with 7–27% of costs due to increased FCR (Blake *et al.*, 2020).

Eimeria species that infect chickens are very common, but the incidence of clinical and sub-clinical coccidiosis is unclear and known to vary between regions. It has been estimated that 5% of flocks suffer clinical coccidiosis, with a further 20% experiencing sub-clinical coccidiosis (Zhang *et al.*, 2013). Figures from other studies have suggested a wide range, with 3–80% of flocks affected by coccidiosis (Blake *et al.*, 2020). Our survey in Algeria revealed considerable variation in the incidence of coccidiosis among different poultry categories with 17.5%, 27.5% and 10.0% of broiler, broiler breeder and laying hen/laying hen breeder flocks affected. Studies conducted in specific countries have also provided estimates of coccidiosis prevalence at the farm and flock levels. For example, in Iran, the prevalence of sub-clinical coccidiosis in broiler farms was reported to be 75%, with *E. acervulina* being most common (65.5%) (Shirzad *et al.*, 2011). In Romania, the presence of parasites at the flock and farm levels in broilers was reported to be 91% and 92%, respectively (Györke *et al.*, 2013). The high frequency of coccidiosis in Algeria, as highlighted in our survey, has direct implications for treatment costs and associated mortality rates. Therapeutic treatment costs were estimated at £0.06 per broiler and £0.16 for other poultry categories. Extrapolating these results to the year 2022, we can estimate that approximately 43.86 million broiler, 534,600 broiler breeder, 2.4 million layer, and 29,040 layer breeder chickens required treatment for coccidiosis in Algeria. Furthermore, a major concern lies in the significant mortality rate recorded in farms affected by coccidiosis, reported to be 2.7% for broilers in Algeria. Extrapolating this figure to the total population of 43.86 million birds affected by coccidiosis results in an estimated mortality of 1.24 million broilers. These data attest to the major impact of coccidial infection on the health and productivity of broilers in Algeria, leading to annual losses estimated at £4 million.

The significant disparity between losses attributed to coccidiosis and the costs associated with prevention raises economic questions. Treatment and poultry loss costs can accumulate rapidly due to the high prevalence of coccidiosis, necessitating attention to disease prevention and management (Peek & Landman, 2011; Blake *et al.*, 2020). It highlights potential limitations in current control strategies, revealing technical gaps in the poultry sector (Kleyn & Ciacciariello, 2021; Li *et al.*, 2022), especially concerning the adaptation of chicken lines to the specific environment of Algeria. This observation reinforces the need for a thorough reassessment of current coccidiosis prevention approaches in the country, with a particular focus on the necessary technical adjustments in chicken farming and the improvement of genetic selection for better adaptation to local conditions.

Uncertainty persists regarding the future status of anticoccidial drugs for use with poultry. Consumer- and legislation-driven changes are influencing the range and identity of anticoccidial drugs available for use with partial or even total bans in some regions (Peek & Landman, 2011). The growing interest in "antibiotic-free" food production is expected to increase the use of anticoccidial vaccines and alternative products to control *Eimeria*, and can be expected to influence the future cost of coccidiosis. Alternatives for anticoccidial control include plant or fungal extracts, essential oils, steroids, yeasts, organic minerals, and pre-/probiotics (Peek & Landman, 2011; Rahmani *et al.*, 2021). The cost of these products and quantitative assessment of their benefits will be required in future estimates of the cost of coccidiosis to understand the evolution of anticoccidial control strategies.

To conclude, coccidiosis caused by *Eimeria* remains a substantial financial challenge for the Algerian poultry industry. The analyses described here indicate monetary losses estimated at approximately £86.66 million for the year 2022. The requirement for robust and regionally relevant preventive and control measures to alleviate these financial burdens is clear. Improved understanding of the true costs of coccidiosis can be used to inform development of control strategies that are economically acceptable to industry. A more nuanced understanding of regional variations and the contextual factors prevailing in different regions can be used to refine estimates of the costs of diseases in livestock and poultry.

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