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DOI: https://doi.org/10.1016/j.vetpar.2024.110143

Veterinary Parasitology 327 (2024) 110143

Contents lists available at ScienceDirect

Veterinary Parasitology

journal homepage: www.elsevier.com/locate/vetpar

Prediction of coccidiosis prevalence in extensive backyard chickens in countries and regions of the Horn of Africa

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ARTICLE INFO

Keywords:
Coccidiosis
Chicken
Backyard
Imputation
Climate
Horn of Africa

ABSTRACT

Coccidiosis is one of the leading morbidity causes in chickens, causing a reduction of body weight and egg production. Backyard chickens are at risk of developing clinical and subclinical coccidiosis due to outdoor housing and scavenging behaviour, jeopardizing food security in households. The objectives of this study were to estimate clinical prevalence of coccidiosis at country and regional levels in the Horn of Africa in extensive backyard chickens. A binomial random effects model was developed to impute prevalence of coccidiosis. Previously gathered prevalence data (n = 40) in backyard chickens was used to define the model. Precipitation (OR: 1.09 (95% CI: 1.05–1.13) and the presence of seasonal rainfall (OR: 1.85, 95% CI: 1.27–2.70) significantly increase prevalence. Results showed an overall prevalence of coccidiosis in the Horn of Africa of 0.21 (95% CI: 0.15–0.29). Ethiopia, the Republic of South Sudan and Kenya showed the highest prevalence and Djibouti the lowest. Significant differences between Djibouti and the countries with highest prevalence were found. However, no evidence of a significant difference between the rest of the countries. Kenya and Ethiopia showed larger prevalence differences between regions. Results could assist with the targeting of testing for coccidiosis, the observation for clinical disease of chickens living in specific regions and as a baseline for the evaluation of future control measures.

1. Introduction

More than 80% of the human population in the Horn of Africa live in rural areas and over 75% of those households raise chickens (Tabler et al., 2021). Keeping chickens provides a high quality source of protein for home consumption and generates income to cover basic necessities in the household (Nchinda et al., 2011; Sultana et al., 2012). The Horn of Africa is experiencing a transition from backyard chicken production to more commercial production, mainly driven by an increase in demand and market forces (Vernooij et al., 2018). However, although the ratio of backyard production versus commercial production varies depending on the country (Vernooij et al., 2018), the largest volume of eggs and chicken meat is still produced by extensive village chickens in the Horn of Africa (Tabler et al., 2021).

Parasite diseases are common in extensive backyard chickens (Butcher and Miles, 2019). ***Eimeria*** spp. is a protozoan parasite widely spread throughout the world (Clark et al., 2016) and ubiquitous where chickens are raised (Allen and Fetterer, 2002). ***Eimeria*** spp. is host-specific and, although there are many Eimeria species described, only seven can infect chickens (Chapman et al., 2013). ***Eimeria*** spp. is the causative agent of coccidiosis, an enteric disease in domestic chickens (*Gallus gallus domesticus*) that generates significant economic and animal welfare impacts (Reid et al., 2014). The management and control of coccidiosis can be achieved through animal husbandry, chemoprophylaxis and vaccination (Allen and Fetterer, 2002).

Coccidiosis has ranked within the top 20 relevant diseases in poultry in the Greater Horn of Africa (Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda) (African Development Bank Group, 2010).

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https://doi.org/10.1016/j.vetpar.2024.110143
Received 11 October 2023; Received in revised form 31 January 2024; Accepted 31 January 2024
Available online 3 February 2024

Also, results of a survey conducted to veterinary practitioners in East Africa ranked coccidiosis as the second disease that generates major health constraints in poultry in this geographical region (Campbell et al., 2021). Previous studies have reported a within flock prevalence of coccidiosis ranging from 22.9% to 71.7% in intensive chicken farms in Ethiopia (Abebe and Gugsa, 2018; Abebe et al., 2019), 14.% in intensive chicken farms in Somalia (Jeilani Busuri Mio et al., 2022) and 5.5% in intensive chicken farms in Sudan (Alzib and Ghada, 2017).

Chickens are infected through faecal-oral transmission. Infected chickens shed unsporulated oocysts (non-infectious) through faeces to the environment, where sporulation takes places within two to seven days (López-osorio et al., 2020). Oocysts have a hard wall, formed by two layers mainly composed by proteins, lipids and carbohydrates, that provides resistant properties and favour dispersion (Dantán-González et al., 2015). Environmental conditions such as temperature, humidity and oxygen affect the sporulation process (Waldenstedt et al., 2001). In general, temperatures between 25 to 30 °C in combination with 60–80% of relative humidity facilitate sporulation (Anderson et al., 1976; Attree et al., 2021; Fatoba and Adeleke, 2018; You, 2014). However, lower temperatures and drier conditions have been associated with retarded sporulation (Musa et al., 2010). Oocysts can survive in temperatures as low as 4 °C(Anderson et al., 1976) but temperatures above 50 °C can cause morphological alterations and impair the oocyst integrity (Anderson et al., 1976; Schneiders et al., 2020). After sporulation, the oocysts contain sporozoites (infectious material). With appropriate environmental conditions, sporulated oocysts can remain viable in the environment from months to years (Price, 2012). Sporulated oocysts can be ingested by uninfected chickens through contaminated water, food or faeces and spread by people and fomites between the chicken premises. Once the sporulated oocysts are in the hosts' intestinal tract, the sporozoites are released, starting the life cycle of the parasite (Belli et al., 2006).

Infected chickens can develop different forms of coccidiosis depending on the severity of the infection, which mainly depends on the load of oocysts (infectious dose) ingested by the host, parasite species, age and immune system (Attree et al., 2021). Clinical coccidiosis develops when sporulated oocysts are ingested and as a result of the intestinal damage, bloody diarrhoea and in severe cases, death (Reid, 1990). In this case, chickens are more likely to develop secondary bacterial infections due to tissue damage, which allows bacteria to penetrate the intestinal barrier. In general, clinical coccidiosis is self-limiting and the birds that recover develop immunity, although their production level may not be regained (Fanatico, 2006). Subclinical coccidiosis develops with an ingestion of less than 100 oocysts and manifests with a reduction in body weight and egg production (Reid, 1990). This form of coccidiosis is difficult to diagnose and represents the highest fraction of total economic losses in the industry (Abdisa et al., 2017).

Backyard chickens are generally raised in open housing with access to the outdoor area, which allows them to scavenge without any restriction (FAO, 2004). These conditions facilitate contact with infected sporulated oocysts and infection with *Eimeria* spp. The repeated exposure to different *Eimeria* spp. can maintain chickens' immunity to particular species of *Eimeria* and lead to subclinical coccidiosis (Ashenafi et al., 2004).

The Global Burden of Animal Diseases (GBADs) programme (http://animalhealthmetrics.org/) aims to enhance animal health and welfare and the subsequent societal outcomes. One of the GBADs' endeavours is to estimate the burden of disease in different livestock species and production systems and, for this, estimating prevalence of relevant diseases is required. As part of the GBADs' work, the objective of this study is to estimate the clinical prevalence of coccidiosis in extensive backyard chickens at country and regional levels in the Horn of Africa using climatic factors.

2. Material and methods

2.1. Data selection and extraction

2.1.1. Production system

This study targets backyard farms (including free-roaming chicken farms) following the FAO definition (sector 4) (FAO, 2007). A low biosecurity level and contact with other wildlife and birds were considered essential selection criteria.

2.1.2. Countries

The countries considered in the Horn of Africa include Djibouti, Eritrea, Ethiopia, Kenya, Republic of South Sudan, Republic of Sudan and Somalia. Each country was broken down into their principal administrative divisions. Depending on the country, these were counties, governorates, provinces, regions or states. For simplification, the term "region" is used throughout the manuscript to refer to "principal administrative division".

2.1.3. Response variable

Prevalence data of coccidiosis was gathered during the screening process of a systematic literature review whose aim was to identify and evaluate studies providing data to assess the impact of diseases and other causes of morbidity or mortality in backyard chickens (*Gallus gallus domesticus*) in low-income and middle-income countries (LMIC). During the screening process, a dataset containing prevalence data of chicken diseases was built. Only prevalence data from chickens that had gone through diagnoses using laboratory techniques were gathered. The review covered the ten most spoken languages in LMIC, a wide range of databases and the search was restricted to data published from 1981 to 2021 inclusive (Muñoz-Gómez et al., 2023). In total, 40 clinical within flock prevalence estimates of *Eimeria* spp. from backyard chickens were collected from 2004 to 2021, out of which 30 were from African countries (Ethiopia (n = 21), Kenya (n = 8), Nigeria (n = 1), South Africa (n = 1)), five from Asian countries (Iraq (n = 2), India (n = 1), Iran (n = 1), China (n = 1)) and four from the Americas (Ecuador (n = 2), Costa Rica (n = 1), Mexico (n = 1)). The range of the flock sample size was 50–2192 chickens. The studies and prevalence data used for this study are available in supplementary material 1.

2.1.4. Predictor variables

A set of potential predictor variables were selected for the model. These included gross domestic product (GDP) per capita, as an indicator of poverty, seasonal rainfall, density of chickens and climatic factors (temperature and precipitation). These variables were hypothesized as the most likely to affect the transmission of coccidiosis.

Data on GDP per capita in United States dollars (USD) from 2004 to 2021 were extracted from the World Bank (WB, 2023) for all the countries included in the Horn of Africa and for those from which prevalence data were gathered. Data on GDP per capita is defined at country level and was assumed to be the same in regions within a country.

Seasonal rainfall was defined as irregular distribution of rainfall during a normal year and was coded as a binary variable. The updated Köppen climate classification (Beck et al., 2018) was used to identify regions with seasonal rainfall. The selection of climates and regions with seasonal rainfall are available in supplementary material 2.

Data on the population density of extensive backyard chickens were obtained from Gilbert *et al.* (Gilbert et al., 2015). This study estimated the density of chickens raised under extensive production systems (village or backyard production with low biosecurity level) in geographic information system (GIS) from 2010. Density was defined as the number of birds per square kilometre, and it was estimated for each of the regions of the countries included in the Horn of Africa and for those regions from countries for which prevalence data were gathered. Density was computed considering the total area of each region. As

(Gilbert et al., 2015) estimated density was only available from 2010 and, to our knowledge this is the only standardized source on density values for extensive chickens, the same density of chickens was assumed for the period 2004–2021.

Data on climatic factors were obtained from the historical climate database of the Terra Climate project through the "Data Download" web tool (Hegewisch and Abatzoglou, 2022). Data on precipitation (mm), maximum temperature (°C) and minimum temperature (°C) were downloaded for the period 2004–2021 for each of the regions that integrate the countries comprised in the Horn of Africa and for the regions from countries where prevalence data were gathered. The "Data Download" web tool extracts point data from each of the regions. In this study, we assumed that the point data were representative for the whole region.

The following variables on climatic factors were generated based on the previous data. "Precipitation" (mm) was defined as the monthly average precipitation in a year. "Maximum precipitation" (mm) was generated by selecting the maximum monthly precipitation value of each year. "Minimum precipitation" (mm) was determined by selecting the minimum monthly precipitation value of each year. "Minimum temperature" (°C) was defined as the annual average of the monthly minimum temperature. "Minimum minimum temperature" (°C) was generated by selecting the minimum monthly temperature value of each year. "Maximum temperature" (°C) was estimated as the annual average of the monthly maximum temperature. "Maximum maximum temperature" (°C) was generated by selecting the maximum monthly temperature value of each year.

2.2. Data management

Each prevalence estimate was linked to the year and the region of the country where prevalence data were collected. When different studies reported prevalence estimates for the same region of a country and same year, data of predictor variables were duplicated to assign information on predictor variables to each different prevalence estimate. The prevalence estimates were merged when the same study reported several prevalence estimates in the same sample of chickens placed in the same region of the country and same year. As a result, the same data of predictor variables were assigned to a single prevalence estimate.

2.3. Statistical analyses and reporting

2.3.1. Model

Because prevalence data on coccidiosis was not available for every region in the countries of the Horn of Africa, we developed a regression model to impute prevalence for each region and thus, fill that data gap. All the analyses and visualization were performed in RStudio 4.2.4 (Posit team, 2023).

First, univariable relationship between predictor variables and prevalence of *Eimeria* spp. were computed to assess whether they were significant ($p < 0.05$) and therefore, suitable for the model. For this, linear regressions were conducted using the *glm* function of the *stats* R-package (R Core Team, 2013). Predictor variables included GDP per capita, density of chickens, seasonal rainfall, precipitation, maximum precipitation, minimum precipitation, maximum temperature, maximum temperature, minimum temperature, and minimum temperature.

Second, a binomial random effects model was developed using prevalence of coccidiosis as a response variable from studies collected during the screening process of a systematic literature review and data from the regions where those prevalence estimates were collected as predictor variables. The random effect component was defined by the studies. The flock sample size was weighted in the regression model. This model aimed to derive estimates based on the relationship between the prevalence reported on coccidiosis and characteristics on predictors at regional level. The assumption of this model is that regions with similar predictor variables have similar disease patterns. Table 1 display summary information on the predictors at country level. The final predictor variables included in the model were chosen to produce the lowest Akaike Information Criterion (AIC) value and the highest pseudo-R^2.

The model was developed using the *glmmTMB* package (Brooks et al., 2017) and residuals were validated using the *DHARMa* package (Hartig, 2016). Results of the residuals simulation are available in supplementary material 2.

Third, mean prevalence of coccidiosis and their 95% confidence interval (CI) were imputed for all the regions of the countries in the Horn of Africa using the *predict* function of the *stats* R-package (R Core Team, 2013). Mean values and their standard errors were obtained in logit odds ratio and then transformed into proportions using the *inv.logit* function of the boot package (Canty and Ripley, 2022). CI for a mean were estimated using the standard errors (Altman and Bland, 2005). The dataset gathering imputed values and values of the variables used in the model can be accessed in supplementary material 3. Mean prevalence and 95% CIs in each country were computed as the average of the mean prevalence and CIs of all the regions within the country.

The model was validated using a cross-validation approach. For this, two prevalence estimates from countries out of the Horn of Africa were excluded from the dataset in two different rounds. In each round, the model was run and values of coccidiosis prevalence for all regions of the Horn of Africa were imputed. Results of coccidiosis prevalence were similar and they are available in the supplementary material 4.

2.3.2. Sensitivity analysis

A sensitivity analysis was conducted following three scenarios, which were defined by modifying baseline precipitation values. For each scenario, mean prevalence of coccidiosis and its 95% CI were imputed for each region of the countries in the Horn of Africa.

For scenario 1, baseline precipitation was increased by 10%. For scenario 2 and 3, baseline precipitation was increased by 20% and 30%, respectively. These increases in precipitation are long-term projections already envisioned in the Horn of Africa (IPCC, 2021; WMO, 2020).

2.3.3. Visualization

Maps were downloaded from the global spatial database of Global Administrative Areas (GADM) (University of California, 2022). Graphs and maps were produced using *ggplot2* package (Wickham et al., 2022).

3. Results

A summary of the model output is presented in Table 2.

The overall estimated mean prevalence of coccidiosis in the Horn of Africa was 0.21 (95% CI: 0.15–0.29). For the period 2004–2021, the estimated mean prevalence was relatively constant in countries of the Horn of Africa (Fig. 1). The general imputed prevalence of coccidiosis in Ethiopia (0.28, 95% CI: 0.21–0.35), Republic of South Sudan (0.27, 95% CI: 0.21–0.35) and Kenya (0.27, 95% CI: 0.20–0.35) were the highest, followed by Eritrea (0.20, 95% CI: 0.15–0.28), Republic of Sudan (0.17, 95% CI: 0.12–0.25) and Somalia (0.17, 95% CI: 0.12–0.25) and, Djibouti with 0.11 (95% CI: 0.06–0.19) (Fig. 2).

Fig. 3 shows the regional imputed prevalence of coccidiosis in the Horn of Africa. Within the countries, Ethiopia and Kenya showed the largest difference between regions, with regions ranging from 0.00 to 0.45 prevalence. The Republic of South Sudan was the only country where prevalence was homogeneous in all the regions, ranging from 0.16 to 0.30. The rest of the countries, namely, Republic of Sudan, Eritrea and Somalia showed regions with a prevalence of coccidiosis ranging from 0.00 to 0.30. Imputed prevalence values of coccidiosis at regional level can be found in supplementary material 5.

Results of the three scenarios of the sensitivity analysis showed a similar mean prevalence in all the countries of the Horn of Africa, compared to the baseline (Table 3). Scenario 1 (Fig. 4) represented a low

Table 1
Summary of predictor variables defined at country level included in the model.

Predictor variables	Countries						
	Ethiopia	Republic of South Sudan	Kenya	Eritrea	Republic of Sudan	Somalia	Djibouti
Precipitation (cm) (period 2004-2021)							
Mean (SD)	10.44 (6.83)	8.93 (1.95)	11.10 (5.70)	4.22 (1.73)	4.05 (2.85)	3.69 (2.04)	1.56 (0.70)
Median (IQR)	9.95 (6.53-13.23)	8.91 (7.76-9.98)	10.25 (6.72-14.72)	3.95 (2.96-5.31)	3.81 (1.41-6.52)	3.65 (1.93-5.04)	1.52 (0.96-2.03)
Minimum	1.83	4.40	1.35	1.15	0.01	0.44	0.25
Maximum	78.13	14.209/11	29.36	9.88	11.00	9.90	3.58
Seasonal rainfall							
Frequency (%, n * */N *)	81.82 (9/11)	100.00 (10/10)	65.96 (31/47)	66.67 (4/6)	50.00 (9/18)	50.00 (9/18)	0.00 (0/6)

n **: number of regions in the country with seasonal rainfall; N * : total number of regions in the country.

Table 2
Summary output of the binomial random effects model.

Predictor variable	*Estimate (Odds Ratio)*	*95% CI*	*p-value*
(Intercept)	0.11	0.06-0.21	< 0.001
Precipitation (cm)	1.09	1.05-1.13	< 0.001
Seasonal rainfall [1]	1.85	1.27-2.70	0.001
Random Effects			
Random effect variance (σ^2)	3.29		
Random intercept variance (τ_{00})	0.96		
Intraclass correlation coefficient (ICC)	0.23		
N study	32		
Observations	38		
Marginal R^2/ Conditional R^2	0.033/0.251		

increase of 10% in the monthly average precipitation in a year, while for scenario 2 (Figs. 5) and 3 (Fig. 6), that increase was 20% and 30%, respectively. Predicted prevalence at regional level for each scenario can be found in supplementary material 6 (scenario 1), supplementary material 7 (scenario 2) and supplementary material 8 (scenario 3).

4. Discussion

This study is a first attempt to predict regional and country level clinical prevalence of coccidiosis in extensive backyard chickens from the Horn of Africa using climatic factors. The climatic factors included in our model were "precipitation" (OR 1.09, 95% CI: 1.05–1.13) and "seasonal rainfall" (OR 1.85, 95% CI: 1.27–2.70), both predictors associated with a significant increase in the prevalence of coccidiosis. The literature also supports these results. Precipitation, as a proxy of humidity, is one of the key environmental conditions that affects the sporulation process of *Eimeria* spp. (Waldenstedt et al., 2001) and

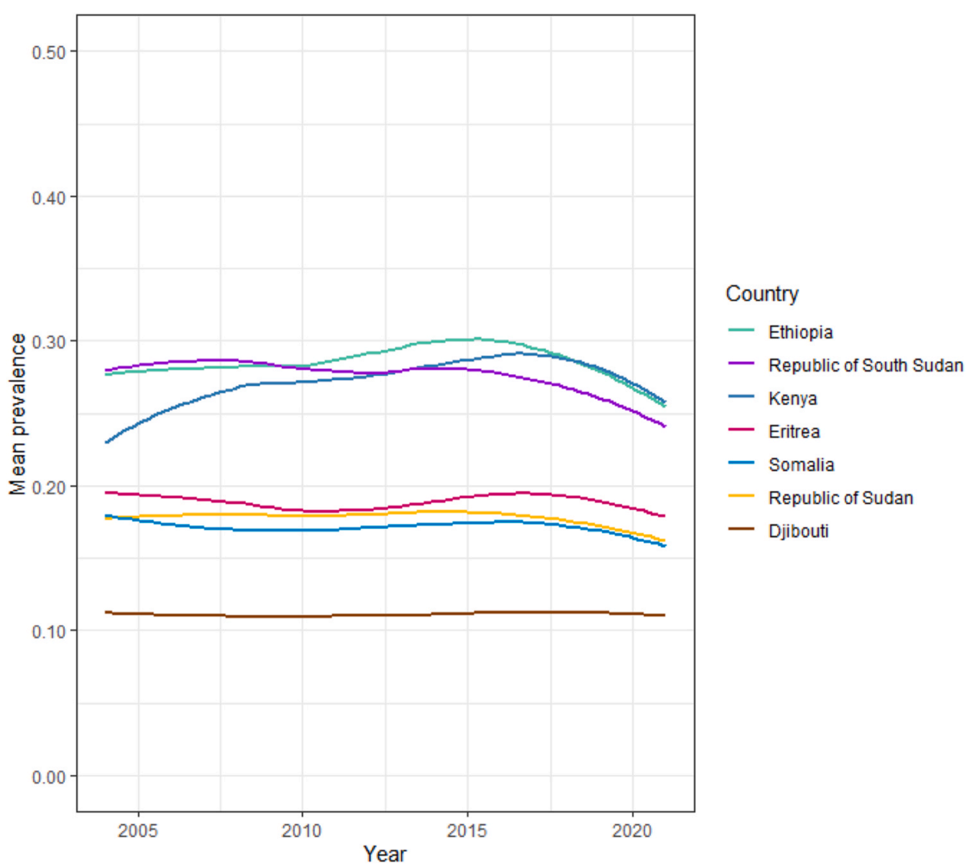

Fig. 1. Mean prevalence of coccidiosis (2004–2021) in countries of the Horn of Africa.

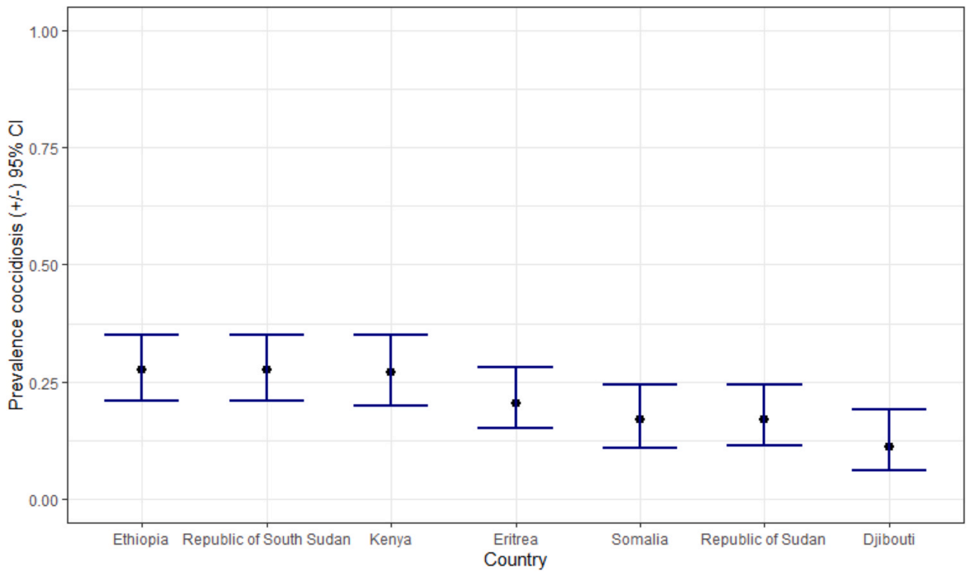

Fig. 2. Aggregated prevalence of coccidiosis (2001–2021) in countries of the Horn of Africa.

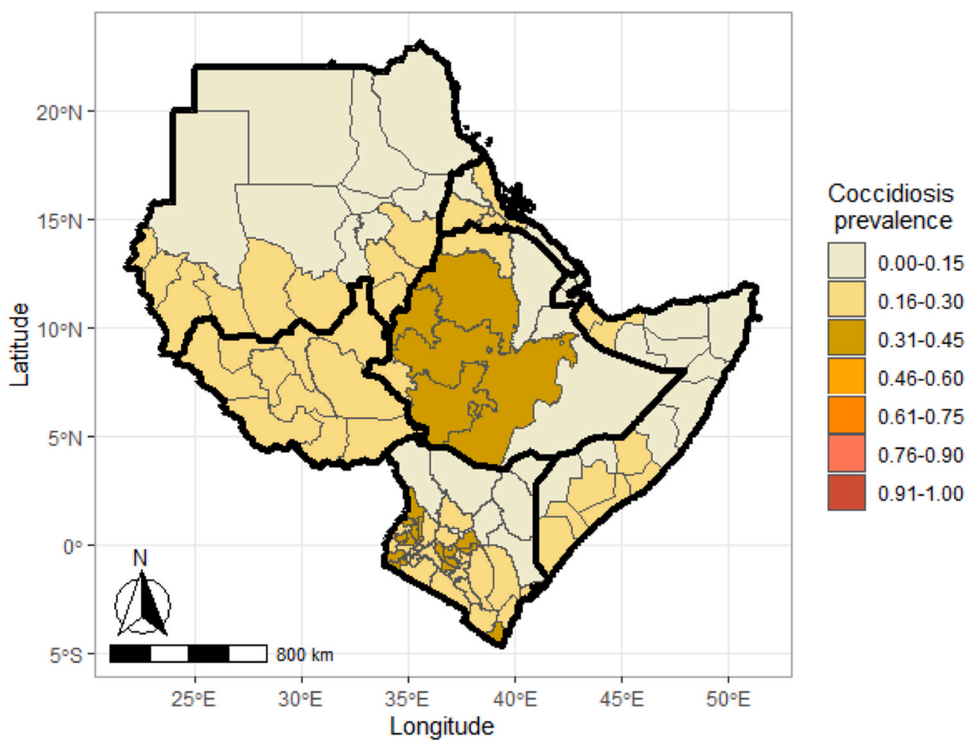

Fig. 3. Predicted mean prevalence of coccidiosis in countries of the Horn of Africa (baseline).

therefore, disease transmission. Also, the presence of seasonal rainfall impacts the prevalence of coccidiosis within the year, increasing during rainy seasons and decreasing during dry seasons (Awais et al., 2012; Olanrewaju et al., 2015).

Our model shows differences between the random effect variance and the random intercept variance and, this is captured by the intraclass correlation coefficient (ICC). The difference between the two measures can be due to a difference in the size of the studies (i.e., number of observations within groups) and the accuracy to estimate the slope coefficients (Lorah, 2022). This variation in the studies size is due to the nature of the available data that we found. In the model, the flock sample size of the studies is weighted, meaning that larger sample size provides higher certainty than small sample size. The rationale for this adjustment was because larger samples tend to yield more precise estimates than smaller samples. There was no association between flock size and prevalence among the selected studies. Although the difference between variances is not large but nevertheless, noticeable, we should consider that as more studies become available and the model is updated, the predictor coefficients might change.

The overall estimated prevalence in the Horn of Africa was 0.21 (95% CI: 0.15–0.29), with Ethiopia, the Republic of South Sudan and Kenya being the countries with the highest prevalence and Djibouti the lowest. Significant differences between Djibouti and the countries with the highest prevalence were found. However, no evidence of significant

Table 3
Results of the sensitivity analysis and baseline.

Scenarios Characteristics	Scenario 1 + 10% precipitation	Scenario 2 + 20% precipitation	Scenario 3 + 30% precipitation	Baseline
Country	Mean prevalence of coccidiosis (95% CI)			
Ethiopia	0.30 (0.23-0.38)	0.31 (0.24-0.40)	0.33 (0.25-0.42)	0.28 (0.21-0.35)
Republic of South Sudan	0.29 (0.22-0.37)	0.30 (0.23-0.38)	0.31 (0.24-0.40)	0.27 (0.21-0.35)
Kenya	0.29 (0.21-0.37)	0.30 (0.23-0.39)	0.32 (0.24-0.41)	0.27 (0.20-0.35)
Eritrea	0.19 (0.14-0.27)	0.20 (0.14-0.27)	0.20 (0.14-0.28)	0.20 (0.15-0.28)
Somalia	0.18 (0.12-0.25)	0.18 (0.12-0.26)	0.18 (0.13-0.26)	0.17 (0.12-0.25)
Republic of Sudan	0.18 (0.13-0.26)	0.19 (0.13-0.26)	0.19 (0.14-0.27)	0.17 (0.12-0.25)
Djibouti	0.11 (0.06-0.19)	0.11 (0.06-0.19)	0.11 (0.07-0.19)	0.11 (0.06-0.19)
Overall	0.22 (0.16-0.30)	0.23 (0.16-0.31)	0.23 (0.17-0.32)	0.21 (0.15-0.29)

difference between the rest of the countries as confidence intervals overlap.

At the regional level, we observe that Kenya and Ethiopia present larger differences between regions while in the case of Djibouti and the Republic of South Sudan, regional estimates of coccidiosis are similar. This could be due to the variation in the topography that Ethiopia and Kenya present with highlands, lowlands, and plateau and, consequently, different precipitation and seasonal rainfall patterns. In contrast, Djibouti and the Republic of South Sudan are mostly covered with similar precipitation and seasonality in the regions and as a result, coccidiosis prevalence. However, we acknowledge that there might be other factors such as management practices in farms that are not captured in our model and that might have an impact on the prevalence in chickens. Due to a lack of information regarding management practices, among backyard farms in the Horn of Africa and among the selected studies, a predictor variable specifically for management practices was not included in the study. However, as an indicator of poverty, "GDP per capita", which is an indicative of financial resources, was included as a predictor variable. Because, in the backyard farming sector, financial resources in the household would be closely linked to the resources allowable to animal health control on the farm. Despite this, the GDP per capita variable was not selected during the model building process because its inclusion with other variables did not bring the best fit for the data.

Thus, the results of this study could be used as a proxy to encourage testing of coccidiosis in specific regions as well as observation of clinical cases.

The sensitivity analysis shows that an increase between 10% to 30% in the monthly average precipitation in a year in countries of the Horn of Africa does not affect the country prevalence of coccidiosis in extensive backyard chickens. However, we observe a slightly increased prevalence in the regions within the countries, especially in Ethiopia and Kenya. The coefficient of the predictor "precipitation" shows a low significant increase (OR 1.09, 95% CI: 1.05–1.13) of coccidiosis prevalence and this is reflected in the results of the sensitivity analysis. The increase of precipitation between 10% to 30% are expected to occur in the Horn of Africa as the temperature increases due to global warming (IPCC, 2023). These results could be used to predict coccidiosis prevalence in the future. However, these results should be interpreted with caution. As the model is updated with newly available data, results may change. Therefore, with the current available data, the increase in precipitation leads to a slight increase in the prevalence of coccidiosis at the regional level in Ethiopia and Kenya, although not at country level.

Coccidiosis is one of the leading morbidity causes in chickens (Reid et al., 2014) and backyard chickens are at high risk of developing

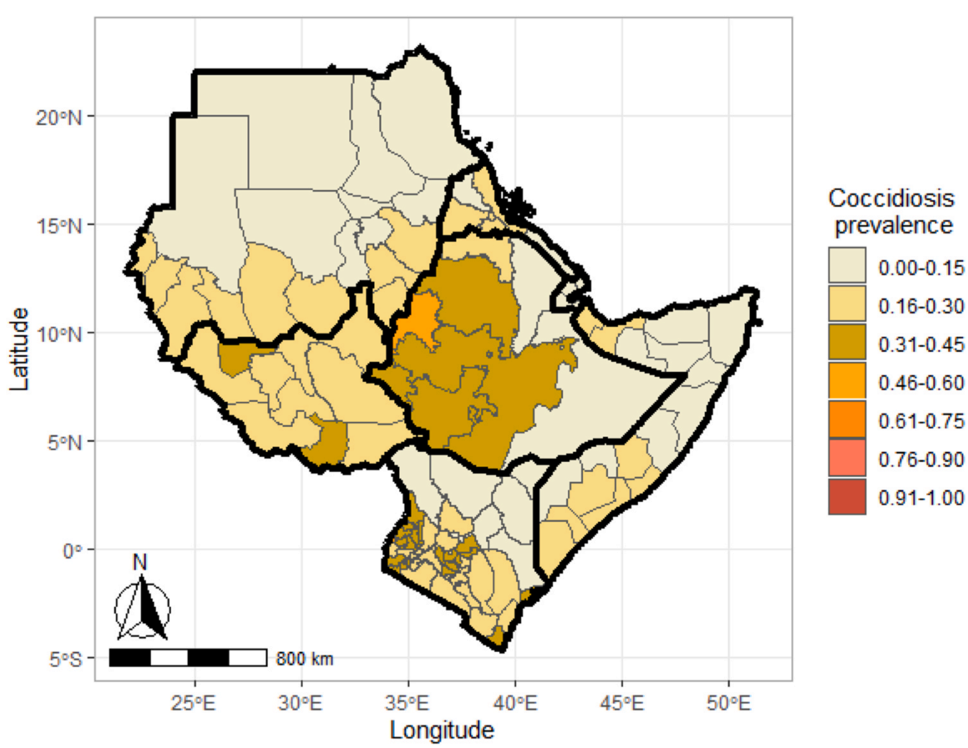

Fig. 4. Predicted mean prevalence of coccidiosis in regions of countries of the Horn of Africa in scenario 1.

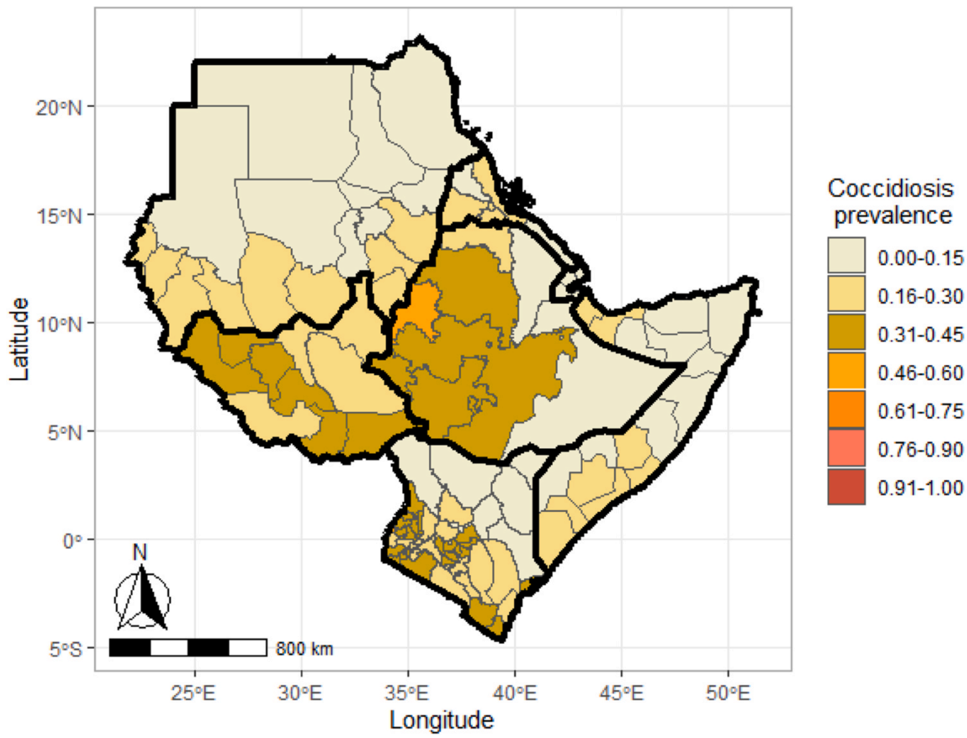

Fig. 5. Predicted mean prevalence of coccidiosis in regions of countries of the Horn of Africa in scenario 2.

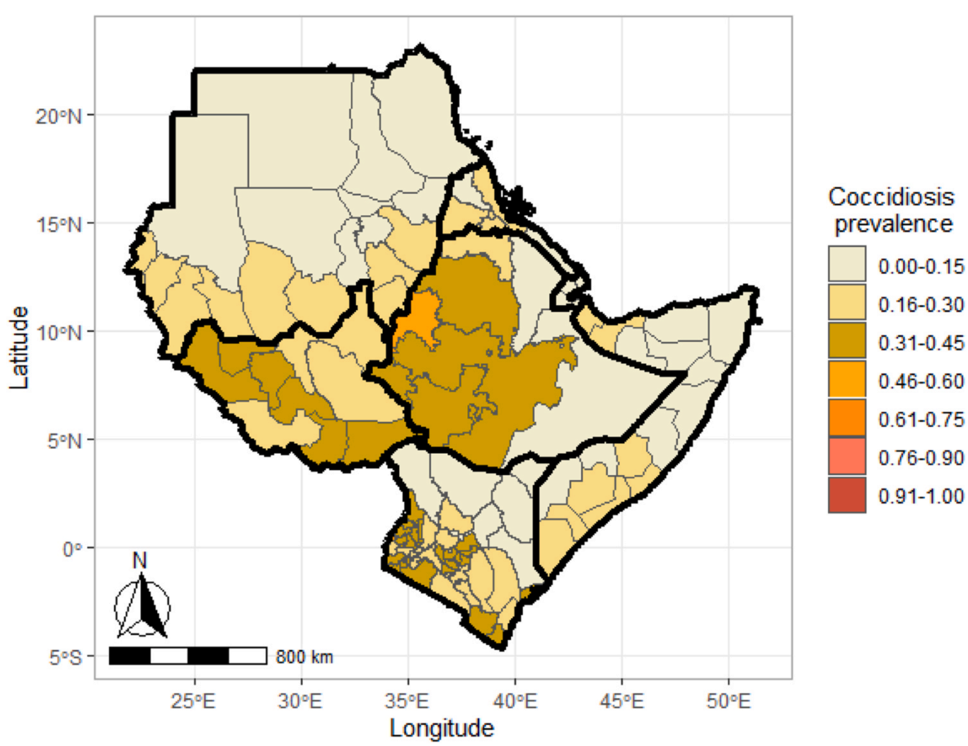

Fig. 6. Predicted mean prevalence of coccidiosis in regions of countries of the Horn of Africa in scenario 3.

clinical and subclinical coccidiosis because of the outdoor access and scavenging behaviour (Ashenafi et al., 2004). The economic impact of coccidiosis in backyard chicken farms has not been estimated yet and one of the reasons is the lack of available data at farm level (Fornace et al., 2013). However, we know that this disease is one of the most economic relevant to the industry (£7.7-£13.0 billion every year globally) (Blake et al., 2020). Considering this and that coccidiosis can be accompanied by secondary bacterial infections(Fanatico, 2006), production losses are unlikely to be negligible in backyard farms, and consequently, food security can be jeopardized in the households.

The main control measures for coccidiosis, including husbandry (biosecurity, removal of caked litter, aeration), chemoprophylactic treatment and vaccination (Tewari and Maharana, 2011), are challenging to implement in subsistence systems like backyard chicken farming in developing countries due to financial constraints. Some economically effective measures to lower the impact of non-viral diseases in backyard systems have been described, such as the improvement of nutrition and changes in the management practices (Luu et al., 2013). Therefore, there is a need to foster accessible options to control coccidiosis in backyard farms from developing countries.

In industrialised countries, the shift from cage systems to open housing systems to improve animal welfare has led to an increasing concern about the rise of parasites in poultry. As the chickens are more exposed to the environment, the levels of infections of parasites such as *Ascaridia galli* increases (Höglund et al., 2023). In the European Union, coccidiostats treatment has been banned for organic farming as a control measure for coccidiosis (EP, 2018) and as a result, vaccination is gaining support within the organic sector (FVE, 2022). In this transition from cage system to open housing and in organic farming, it is difficult to implement all-in, all-out management practices. In this scenario, our model could be used to provide a proxy for baseline estimations of coccidiosis prevalence before vaccination is implemented.

This study has some limitations. We predicted coccidiosis prevalence in countries where no data were available, and this comes with large uncertainty as this prediction assumes that *Eimeria* spp. is ubiquitous. However, this study provides prevalence data in the absence of surveillance studies in low resource settings. A further limitation is that we assumed that point estimates of climatic variables are representative of the whole region. We explored different databases on climatic factors including the Global Precipitation Climatology Centre (GPCC), the World Meteorological Organization (WMO), the Copernicus Climate Data Store (CCDS), the World Bank Climate Change Knowledge Portal (WBCCK), Tropical Rainfall Measuring Mission (TRMM), the National Oceanic and Atmospheric Administration (NOAA) and the Terra Climate (TC) and we selected the latter. Some reasons why none of the remaining databases were selected include outdated data (GPCC data only available until 2000, TRMM data only until 2017), no data available on the countries of interest (case of NOAA, WBCCK, GPCC, CCDS) and the inconvenience of only being able to download city-level data (WMO). As a result, we chose the Terra Climate database as the most convenient, the most complete geographically and most efficient in terms of time. Nevertheless, the coordinates (latitude and longitude) of the climatic variable values are available in the supplementary material 3.

Epidemiological studies on the prevalence of coccidiosis are useful tools for disease control and prevention (Snyder et al., 2021). Our study provides prevalence estimates at regional and country level in the Horn of Africa. These results could assist with the targeting of testing for *Eimeria* spp. and the observation for clinical disease of chickens living in specific regions. In our model, we ignored potential control options that could be in place because the frequency of its implementation has been described as rather low (Ketema and Fasil, 2019; Luu et al., 2013). If this holds true, results of this study could be used as a proxy for baseline before initial control measures are implemented. This baseline could help in the evaluation of the implemented control measures.

Within the Global Burden of Animal Diseases programme (https://gbads.woah.org/), we are aiming to estimate the burden of diseases in different livestock production systems. Future research will include the continued imputation of prevalence of other diseases in backyard chickens. Results of regional prevalence estimates, together with other input data, will later be used in a comorbidity model (Rasmussen et al., 2022) to account for the productivity and mortality losses attributable to each disease in backyard chickens.

5. Conclusions

Our study is a first attempt to impute prevalence of coccidiosis in extensively reared backyard chickens from regions in the Horn of Africa using climatic factors. Ethiopia, the Republic of South Sudan and Kenya showed the highest prevalence and Djibouti the lowest. Significant differences between Djibouti and the countries with the highest prevalence were found However, there is no evidence of a significant difference between the rest of the countries. Ethiopia and Kenya showed the largest differences between regions. As more data on coccidiosis prevalence become available, the model and results should be updated. The sensitivity analysis investigating different scenarios of future increased precipitation suggested that precipitation will slightly increase coccidiosis prevalence but without significant differences compared to the baseline. The results of this study could be used to encourage testing in specific regions and to target field observations of clinical disease. Also, when no control measures against coccidiosis are in place, our model could be used to provide predicted prevalence data as a proxy for baseline field study values and thus, feed the evaluation process of control measures.

CRediT authorship contribution statement

Rasmussen Philip: Writing – review & editing, Methodology. **Torgerson Paul R.:** Writing – review & editing, Validation, Supervision, Software, Project administration, Methodology, Funding acquisition, Conceptualization. **Muñoz-Gómez Violeta:** Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Furrer Reinhard:** Writing – review & editing, Validation, Methodology. **Yin Jie:** Writing – review & editing, Data curation. **Shaw Alexandra PM:** Writing – review & editing, Methodology.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

All the data necessary to reproduce results are included in the supplementary material.

Acknowledgements

Authors thank GBADs programme for helpful discussions (https://animalhealthmetrics.org/). This research is supported by the Global Burden of Animal Diseases programme through Grant Agreement Investment ID INV-005366 with the Bill and Melinda Gates Foundation and the UK Foreign, Commonwealth and Development Office (FCDO).

Conflict of Interest

The authors declare no conflict of interest.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.vetpar.2024.110143.

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