

Infectious and parasitic diseases of poultry in Ethiopia: a systematic review and meta-analysis

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ABSTRACT In Ethiopia, poultry production is an important source of domestic food and nutrition security while providing income for nearly 80% of Ethiopians. However, several infectious and parasitic diseases hamper poultry production. To date, evidence on the nationwide burden of specific diseases has not been collated to inform targeting of poultry health interventions. The objective of this systematic review is to summarize and analyze the literature on poultry diseases since 2000. A detailed systematic review protocol was designed according to Cochrane collaboration, Strengthening the Reporting of Observational Studies in Epidemiology (STROBE), and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statements. The review revealed that 14 infectious and parasitic diseases of poultry were reported in 110 published studies from 2000 to 2017, and 81.82% (90/110) of the studies covered 6 diseases: Newcastle disease (ND), infectious bursal disease (IBD), avian coccidiosis, helminth infestation, ecto-parasite infestation, and *Salmonella* infection. The pooled prevalence estimates of ND and IBD were 44% (95% confidence

interval [CI]: 27 to 63) and 41% (95% CI: 23 to 60), respectively. Among the parasitic diseases, avian coccidiosis, helminth infestation, and ecto-parasite infestation had estimated pooled prevalences of 37% (95% CI: 30 to 44), 62% (95% CI: 45 to 78), and 50% (95% CI: 33 to 68), respectively. The pooled prevalence estimate of *Salmonella* infection was found to be 51% (95% CI: 32 to 70). Most of the studies were conducted in central Ethiopia, in the State of Oromia, and focused on extensive farming systems. While the number of studies was low, the overall trend of disease reporting in the literature is increasing ($Y = 0.99X - 3.34$). In conclusion, the high-pooled prevalence estimates of diseases and the scarcity of reported data for all of Ethiopia indicate an important data gap on infectious-disease distribution in the country. While the high-pooled prevalence points towards the need for intervention to control poultry diseases, there is also a need to ensure all diseases that result in production losses and public health risks are studied appropriately in all Ethiopian production systems.

Key words: Ethiopia, infectious and parasitic disease, meta-analysis, poultry, systematic review

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INTRODUCTION

Poultry production has paramount socioeconomic importance in Ethiopia through the provision of eggs and meat which support food and nutrition security at household, regional, and national levels. Moreover, it serves as a source of cash income for about 80% of the Ethiopian population and nationally contributes more than 6.2 billion Ethiopian birr (ETB) (= 206.7 million US dollar [USD]) to the gross domestic product (Shapiro et al., 2015). Additionally, the poultry value chain provides jobs for an estimated 120,000 individuals in addition to the two-thirds of the population en-

gaged in extensive poultry-rearing practices. Women especially have increased economic opportunities through poultry. Sambo et al. (2015) reported that women often directly control the income generated from the sale of chickens and chicken products, with poultry often being their only source of independent income. Poultry also provides raw materials for agro-industries and compared to other livestock sectors, poultry production is considered an attractive business and investment area with a fast and high investment return rate which requires relatively low initial investment capital and land size (African Union, 2014; CSA, 2017).

However, there are several infectious and parasitic diseases which hamper poultry productivity. Growth, commercialization, profitability, and sustainability of poultry business activities operated across Ethiopia are found to be severely constrained due to diseases (Shapiro et al., 2015). Sambo et al. (2015) reported that

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poultry producers ranked disease as the most important problem of the poultry subsector in Ethiopia.

Various studies have been conducted on specific poultry diseases and health constraints in regions of Ethiopia, but the nationwide status and burden of poultry infectious and parasitic diseases have not yet been documented and existing data gaps are poorly understood. However, conducting a nationwide study across diverse agro-ecologies, seasons, and producer populations to answer research questions would be expensive and technically challenging, particularly in resource-poor countries like Ethiopia (Dohoo et al., 2014). The lack of scientific evidence regarding poultry diseases at the national level hinders Ethiopia's ambitious poultry subsector transformation plan. As a result, poultry morbidities (52%) and mortalities (56%) remain high (Shapiro et al., 2015).

Specific infectious and parasitic diseases of poultry are economically important and a threat to public health (Sambo et al., 2015). However, the reported prevalence of infectious and parasitic diseases varies significantly across the country (Luu et al., 2013). For instance, previous researchers reported varying prevalence of Newcastle disease (ND), infectious bursal disease (IBD), coccidiosis, helminth and ecto-parasitic diseases, Marek's disease, *Pasteurella* infection (fowl cholera), and mycoplasma (chronic respiratory disease) in different regions of Ethiopia (Girma et al., 2013; Brena et al., 2016; Sori et al., 2016; Abdi et al., 2017; Demeke et al., 2017; Gebeyeh and Yizengaw, 2017; Hutton et al., 2017; Kebede et al., 2017). In the case of coccidiosis, a wide range of prevalence from a minimum of 16.92% (Molla and Ali, 2015; Molla et al., 2015) to a maximum of 71.67% (Dinka and Tolossa, 2012) was reported in various areas across time.

The significant variations in the reported prevalence of poultry infectious and parasitic diseases, lack of nationwide data, and lack of systemic review and meta-analysis impedes poultry production and the formulation of effective policy to improve the poultry subsector in Ethiopia.

Hence, this systematic review aims to address this important gap in knowledge by collating and analyzing data from the literature regarding poultry diseases in Ethiopia since the year 2000.

MATERIALS AND METHODS

The systematic review protocol was prepared based on the "The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement and Reporting Guidelines for Observational Studies (von Elm et al., 2007) and the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines recommended by Cochrane library (Page and Moher, 2017). The protocol included study search strategy, inclusion criteria, review process, data extraction procedure, and data analysis.

Search Strategy for Identifying Published Studies

After review research questions were formulated considering the population and outcome/prevalence questions format and as per O'Connor and Sargeant (2014), systematic electronic searches were conducted. Key words used were Newcastle disease, infectious bursal disease, Marek's disease, avian coccidiosis, helminth infestation, ecto-parasite infestation, toxoplasmosis, *Salmonella* infections, *Campylobacter* infections, chronic respiratory disease, fowl cholera, avian tuberculosis, *Listeria* infection, *Staphylococcus* infection, *Escherichia coli* infection, poultry, chicken, infectious, parasitic, diseases, health and Ethiopia. PubMed, Google Scholar, VetMed Resource CABI, ScopeMed, and Google were used as search engines.

Inclusion Criteria

The inclusion criteria comprised study design (cross-sectional and longitudinal observational studies), sampling procedure (random), timeframe (published between 2000 and 2017), and language (English).

Review Protocol and Process

The title and abstracts of the identified studies were first reviewed considering the inclusion criteria and preliminary assessment tool (annexed in the supplementary materials). Finally, quality assessment of the full paper, guided by quality assessment criteria which contained checklists and rating scales (annexed in the supplementary materials), was made to select the studies for data extraction. The review was conducted twice by 2 independent researchers to avoid bias in study selection. A detailed assessment of each study was then made (Uman, 2011; Singh, 2017).

Data Extraction

A suitable data extraction template was prepared to collect and organize information from each reviewed study. The information retrieved included author, publication year, breed of chickens, administrative regions (Tigray, Amhara, Oromia, State of Southern Nations Nationalities and People, Addis Ababa, etc.), part of the country (northern, southern, eastern, western, etc.), agro-ecology, production system, study design, diagnostic method, sample size, number of positives, number of negatives, and prevalence (Uman, 2011; Page and Moher, 2017; Singh, 2017).

Data Analysis

The extracted data were cleaned and edited in Microsoft Excel (2013 version), and then imported to and analyzed in STATA 12 software (StataCorp). Descriptive statistics of the number of studies per year

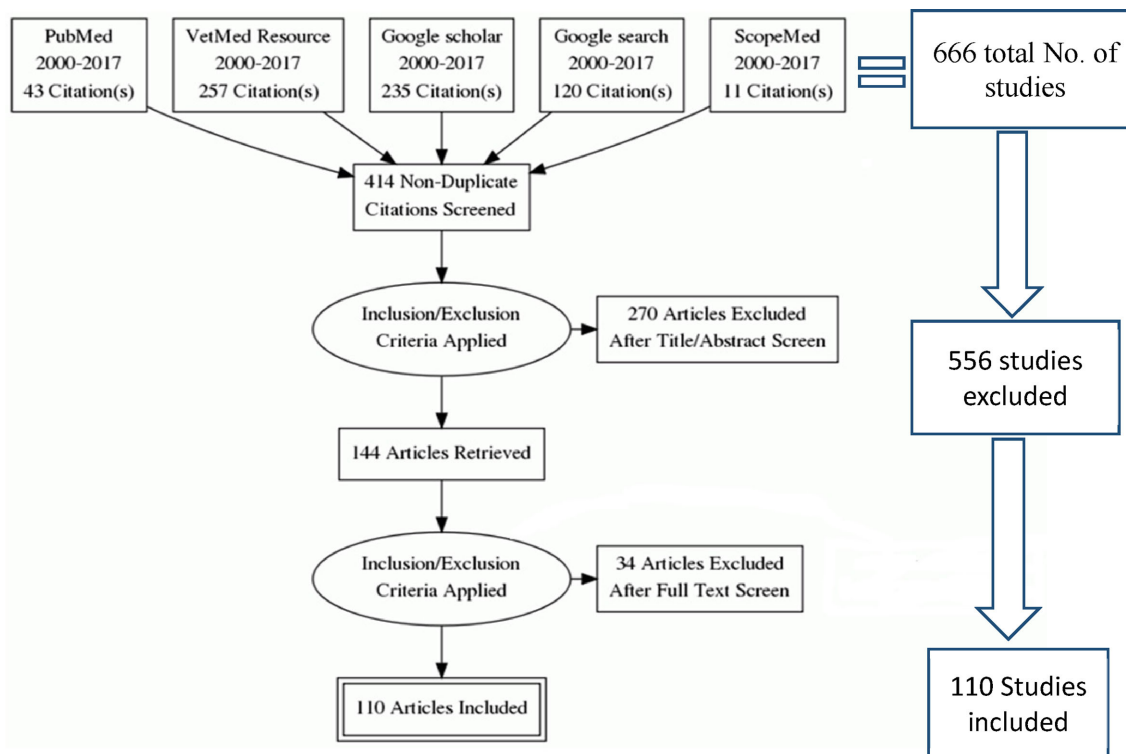


Figure 1. Flowchart illustrating the number of retrieved articles and reviewed studies.

were used to determine the spatiotemporal distribution and characteristics of past research on poultry diseases. Time series model analysis was conducted to understand the trends of the number of studies over time.

For the meta-analysis, a DerSimonian and Laird random effect model was fitted and pooled prevalence at 95% confidence interval (CI) for each infectious and parasitic disease was estimated as described by others (DerSimonian and Laird, 1986). The calculated effect sizes and associated weight of the specific studies were illustrated in forest plots. Cochran's Q-statistic and the I^2 -statistics were used to test heterogeneity between the studies, or whether the variation is due to chance alone. The degree of heterogeneity was considered as low, moderate, and high for I^2 -statistics of <25%, 25–75%, and >75%, respectively. Between-study variance was assessed by Tau (τ^2). As per Borenstein et al. (2009), Begg's and Egger's test statistics in combination with a funnel plot were used to assess publication potential bias. In all of the analyses, statistical significance was set at $P < 0.05$.

RESULTS

Number of Identified and Reviewed Studies

A total of 666 studies were identified through electronic search of 5 databases. Of these, 252 studies were excluded because they were duplicates. The titles and abstracts of the 414 studies were reviewed, and inclu-

sion criteria and the preliminary review tool were applied. From the 414 studies, 270 studies were excluded as they did not fulfill the inclusion criteria. Among the remaining 144 articles, a total of 110 were eligible studies for data extraction and 37, 23, and 70 of them were rated as low-, moderate-, and high-quality studies, respectively. The 110 studies reported on 16 different infectious and parasitic diseases of poultry, resulting in a total sample size of 42,472 chickens/test samples and 5,289 samples were analyzed for different diseases. From the 110 studies, 8 studies reported multiple diseases (multiple pathogens survey) and each report of a specific disease was counted as an independent study (Figure 1).

Characteristics of the Studies

All of the studies ($n = 110$) were of cross-sectional design with random sampling. All of the retrieved and reviewed studies were written in English. The total mean sample size of the 110 studies was 428.76 ± 434.09 chickens. A total of 42,472 chickens were involved in the studies, among which 20,420 (42.68%) were reported to be diseased and or infected by any of the 16 reported infectious and parasitic diseases (annexed in the supplementary materials). The reported type of chicken breeds included in the studies were different local breeds (Ethiopian chicken ecotypes), cross breeds, and exotic breeds. Thirteen of 110 studies (11.82%) did not provide the type of chicken breeds involved in the respective studies. However, the majority of the

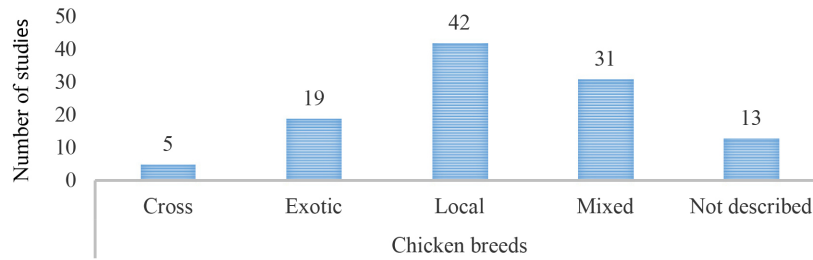


Figure 2. Number of studies by different chicken breeds.

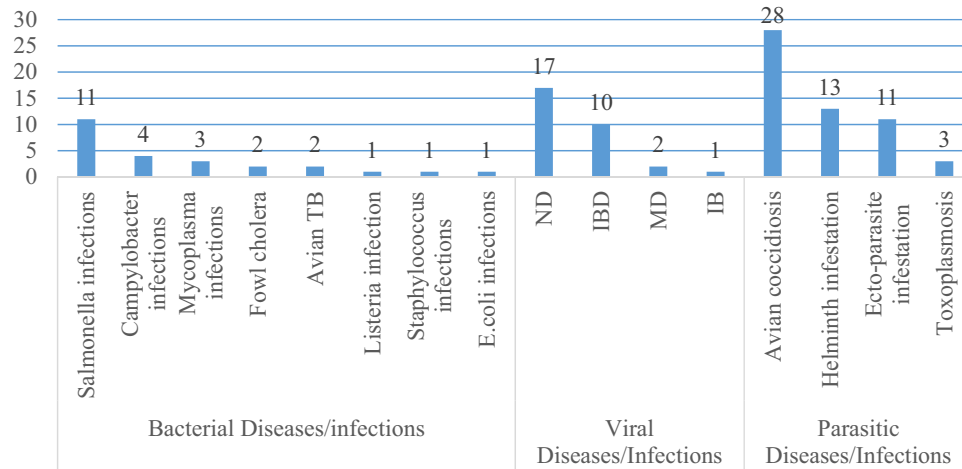


Figure 3. Proportion of the number of studies by specific diseases and categories of pathogens (bacterial, viral and parasitic). Key:- ND = Newcastle diseases, IBD = infectious bursal diseases, MD = Marek's disease, IB = infectious bronchitis.

chickens reported (66.36%) were of local and mixed breeds (Figure 2).

Number of Studies by Type of Infectious and Parasitic Diseases

The review revealed that 16 different infectious and parasitic diseases of poultry were reported on in the 110 studies and the 6 most commonly studied diseases comprised 81.82% of the conducted studies. These top 6 studied diseases were avian coccidiosis, helminth infestations, ecto-parasite infestations, ND, IBD, and salmonellosis. More than a quarter of the studies were on avian coccidiosis; in contrast, only a single study was found in the literature for each of the following diseases: infectious bronchitis, *E. coli* infection, *Listeria* infection, and *Staphylococcus* infection (Figure 3, Table 1). Eight studies looked at several diseases as multi-pathogen surveys.

Spatial Distribution of the Studies

The results of the spatial distribution of the number of studies indicated that the majority of the studies, i.e. 49.1% (54/110), 54.51% (60/110), 79.1% (87/110), and

42.7% (47/110) were reported from central Ethiopia, Oromia Regional State, mid altitude agro-ecology, and extensive farming system, respectively (Figure 4). The majority (62.73%, 69/110) of the diseases/infections were diagnosed by parasitological (31.82%, 35/110) and serological (30.91%, 34/110) tests (Figure 4).

Temporal Distribution of the Studies

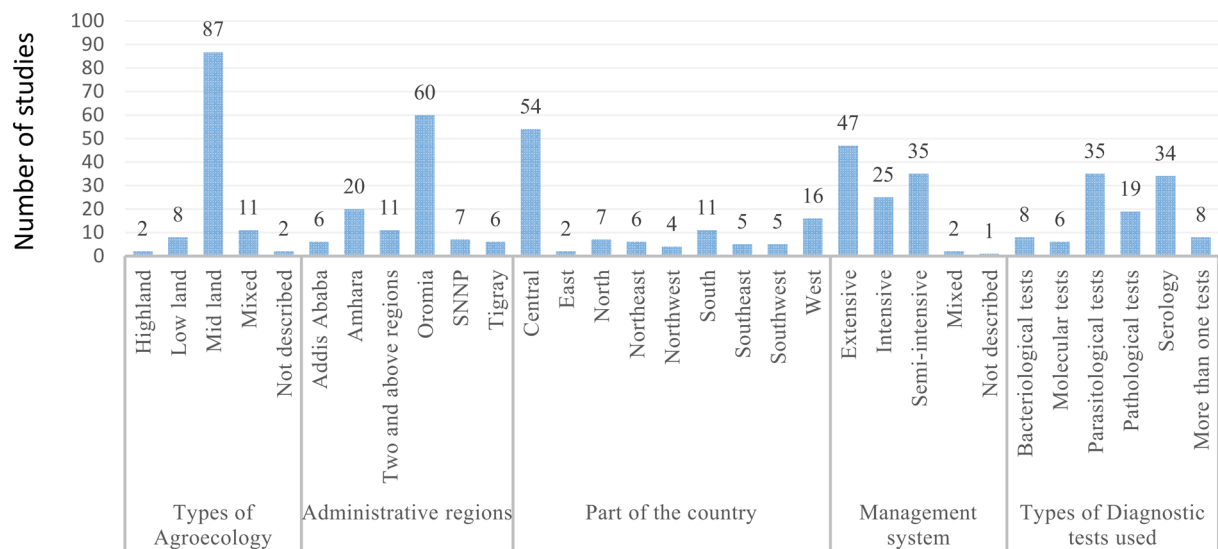
Looking at the distribution of studies published over time, it was noted that 60% of all studies were conducted and published since 2012. In contrast, a distinct paucity of published research was found for the years 2000 to 2008 with only (10%, i.e. 11/110) studies (Figure 5). With regard to the trends of the number of studies over time, a time series model analysis showed an r increasing trend of number of studies by 0.9948 starting from the year 2002 with a trend line of $Y = 0.99X - 3.34$. However, there was considerable variation in the number of studies over time (Figure 5).

Meta-Analysis Results of the Studies

Pooled Prevalence of the Studied Infectious and Parasitic Diseases Based on available data, the

Table 1. Number and proportion of studies, pooled prevalence of infectious and parasitic diseases.

Type of studied diseases		No of studies	Proportion of studies (%)	Sample size	Pooled prevalence (95% CI)	I ² (%)
Viral diseases	ND	17	15.5	7,134	44 (27–63)	99.56
	IBD	10	9.1	9,066	41 (23–60)	99.4
	MD	2	1.8	1,571	34 (32–37)	–
	Infectious bronchitis	1	0.9	117	94.5	–
Parasitic diseases	Avian coccidiosis	28	24.5	13,312	37 (30–44)	98.56
	Helminth infestation	13	11.8	3,634	62 (45–78)	99.30
	Ecto-parasite infestation	11	10.0	4,281	50 (33–68)	99.19
	Toxoplasmosis	3	2.7	909	19 (3–44)	97.59
Bacterial diseases	Salmonella infection	11	10.0	4,526	51 (32–70)	99.24
	<i>Campylobacter</i> infection	4	4.5	931	17 (3–39)	99.28
	CRD	3	2.7	653	47 (13–83)	98.80
	Fowl cholera	2	1.8	1,506	68 (66–71)	–
	Avian tuberculosis	2	1.8	542	4 (3–6)	–
	<i>Listeria</i> infection	1	0.9	115	45.1	–
	<i>Staphylococcus</i> infection	1	0.9	386	54.2	–
	<i>Escherichia coli</i> infection	1	0.9	386	22.4	–
Total		110	100	48,952		

**Figure 4.** Spatial distributions of the number of studies by agro-ecology, administrative regions, part of the country, and management system.

systematic review and meta-analysis allowed determination of pooled prevalence for 12 diseases (3 viral, 4 parasitic, and 5 bacterial diseases). For 3 bacterial and 1 viral diseases, analysis was not possible with only a single paper for each available (Table 1, Figures 6 and 7). Among the viral diseases, for ND and IBD, the 2 most researched diseases, pooled prevalences of 44% (95% CI: 27 to 63, $I^2 = 99.56\%$, $P = 0.00$) and 41% (95% CI: 23 to 60, $I^2 = 99.4$, $P = 0.00$), respectively, was found. The pooled prevalences of avian coccidiosis, helminth infestation, and ecto-parasite infestation as the commonest parasitic diseases were 37% (95% CI: 30 to 44, $I^2 = 98.56\%$, $P = 0.00$), 62% (95% CI: 45 to 78, $I^2 = 99.30\%$, $P = 0.00$), and 50% (95% CI: 33 to 68, $I^2 = 99.19\%$, $P = 0.00$). *Salmonella* and *Campylobacter* infections had pooled prevalences of 51% (95% CI: 32 to 70, $I^2 = 99.24\%$, $P = 0.00$) and 17% (95% CI: 3 to 39,

$I^2 = 99.28\%$, $P = 0.00$), respectively (Table 1, Figures 6 and 7).

As shown in Table 1, fowl cholera (pooled prevalence = 68%) was the disease with the highest prevalence, followed by helminth infestation (pooled prevalence = 62%) and *Salmonella* (pooled prevalence = 51%). However, avian coccidiosis (proportion of the studies = 24%) was reported to be the most studied disease of chickens followed by ND (proportion of the studies = 15.5%). The pooled prevalence of the studied 12 diseases ranges from 4 to 68%; however, the pooled prevalence of almost all of the diseases (10/12 diseases) was more than 20% out of which 5 diseases had a pooled prevalence of 50% and above.

Heterogeneity Statistics The heterogeneity of studies reporting ND, IBD, coccidiosis, helminth infestation, ecto-parasite infestation, and *Salmonella*

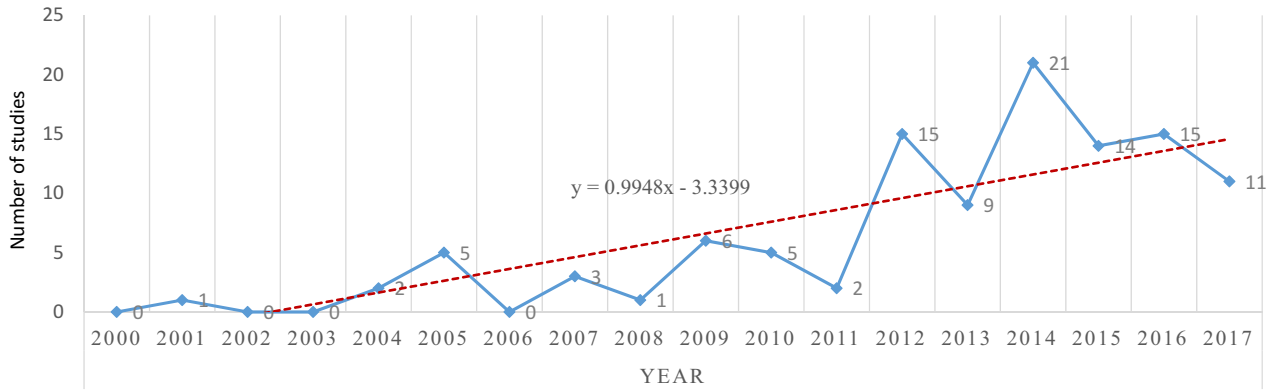


Figure 5. Trend line and trend equation showing growing trend of published studies over years.

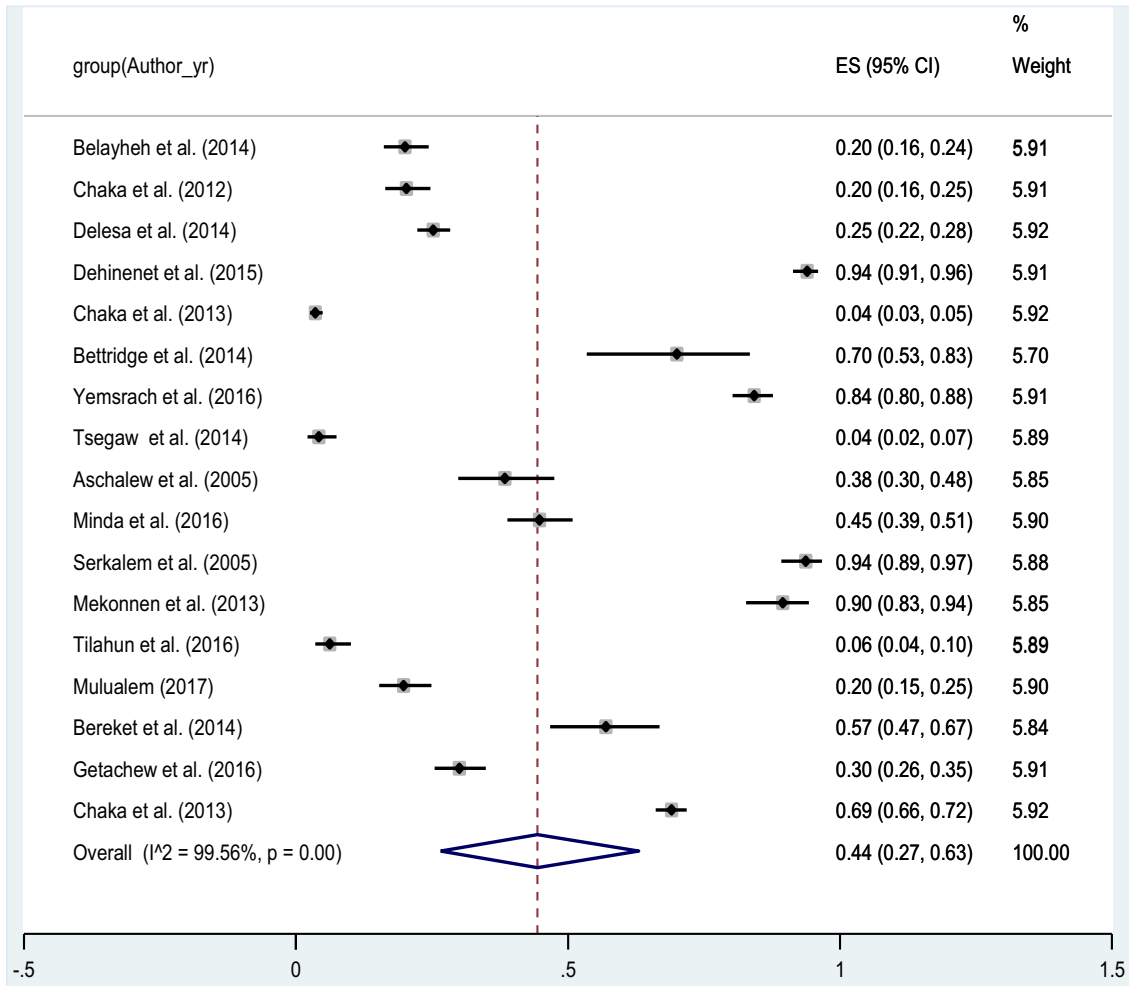


Figure 6. Forest plots showing ES (pooled prevalence) of ND. ES = effect estimate.

infection was statistically assessed using Cochran’s Q-statistic and the I²-statistic. Random effect models calculated the heterogeneity tests (Q²) for ND, IBD, coccidiosis, helminth infestation, ecto-parasite infestation, and *Salmonella* infection to be 655.54 (degree of freedom [DF] = 19, P = 0.00), 321.27 (DF = 9, P = 0.00), 472.90 (DF = 28, P = 0.00), 359.09 (DF = 12, P = 0.00), and 249.18 (DF = 10, P = 0.00) and 269.88

(DF = 10, P = 0.00), respectively. Similarly, the variation in effect estimate (ES) attributable to heterogeneity (I²) of ND, IBD, coccidiosis, helminth infestation, ecto-parasite infestation, and *Salmonella* infection was found to be 99.56, 99.45, 98.56, 99.30, 99.19, and 99.24%, respectively (Table 2). Estimates of between-study variance Tau (τ²) of ND, IBD, coccidiosis, helminth infestation, ecto-parasite infestation,

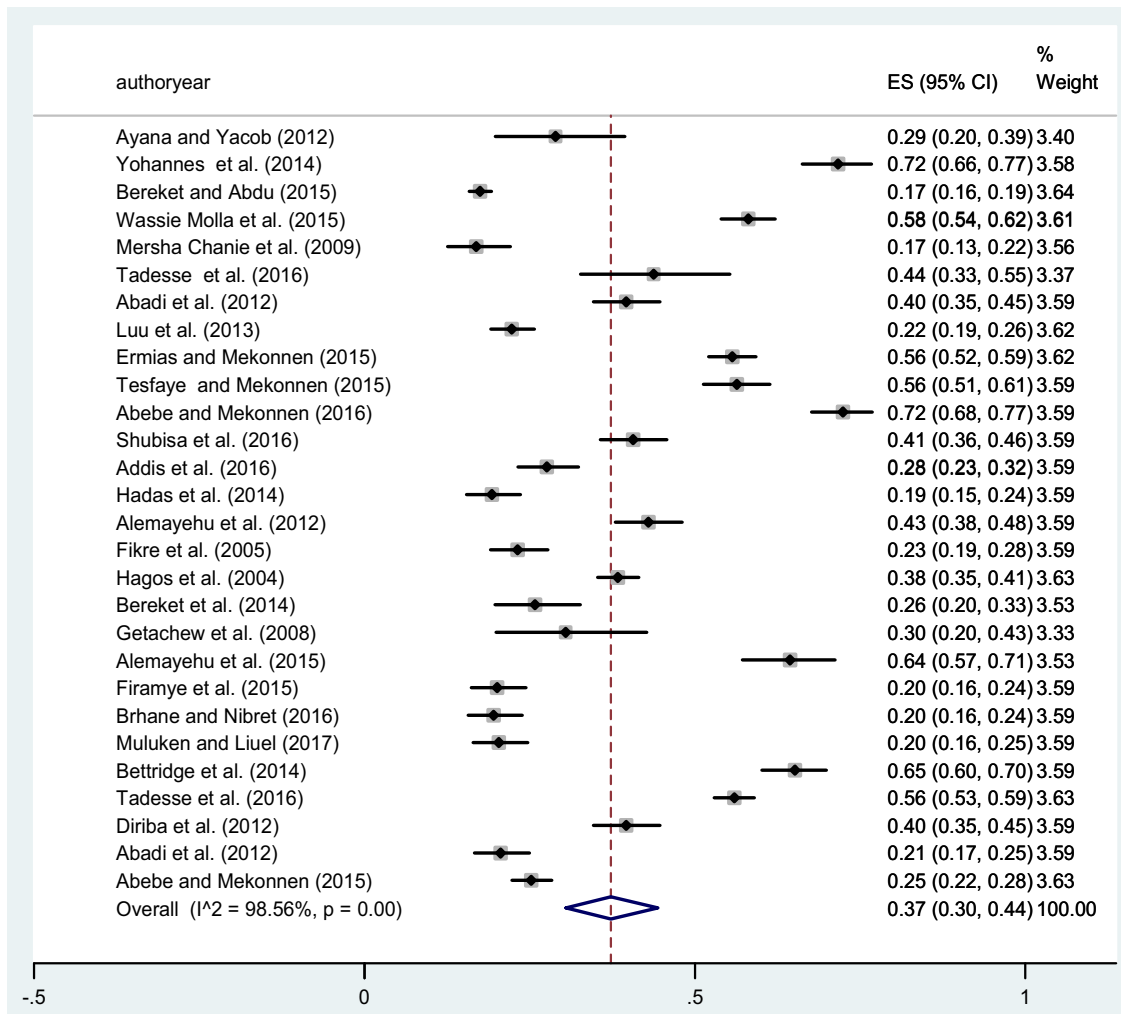


Figure 7. Forest plots showing effect estimates (pooled prevalence) of coccidiosis studies.

Table 2. Tests of heterogeneity among studies (values of Q and I² statistics).

Disease	Pooled prevalence (95% CI)	Heterogeneity test (Q)	(DF)	Q/DF	I ²	P-value of heterogeneity
ND	44 (27–63)	655.538	19	50.78	99.56%	0.00
IBD	41 (23–60)	321.267	9	35.70	99.45%	0.00
<i>Salmonella</i>	51 (32–70)	269.88	10	26.99	99.24%	0.00
Avian coccidiosis	37 (30–44)	472.90	28	16.89	98.56%	0.00
Helminth infestation	62 (45–78)	359.09	12	29.92	99.30%	0.00
Ecto-parasite infestation	50 (33–68)	249.18	10	24.92	99.19%	0.00

and *Salmonella* infection were found to be 0.61, 0.39, 0.15, 0.40, 0.35, and 0.43, respectively. The reported $P = 0.00$ and the values of the I² statistics of the diseases show that there is a high level of heterogeneity between studies.

Tests for Publication Bias The visual inspection of the funnel plots of ND, coccidiosis, and *Salmonella* infections (Figure 8a, c, and d) showed that the majority of the studies are found scattered in the funnel plot with fair symmetry. However, the funnel plots of IBD, and helminth and ecto-parasite infestations (Figure 8b, e, and f) show that the majority of the

studies are found scattered in the funnel plot asymmetrically. The Begg's and Egger's publication bias analysis of the studies reporting ND, coccidiosis, ecto-parasite infestations, and *Salmonella* infections show that the P -values for both tests were found to be 0.650 and 0.344, 0.273 and 0.253, 0.723, and 0.189, and 0.638 and 0.108, respectively. Hence, the statistical insignificance of the P -values of both tests indicates that symmetry exists in the funnel plots and hence, publication bias is unlikely. However, the P -values of Begg's and Egger's statistics of the studies reporting IBD and helminth infestation were calculated to be 0.025 and 0.001, and 0.027 and

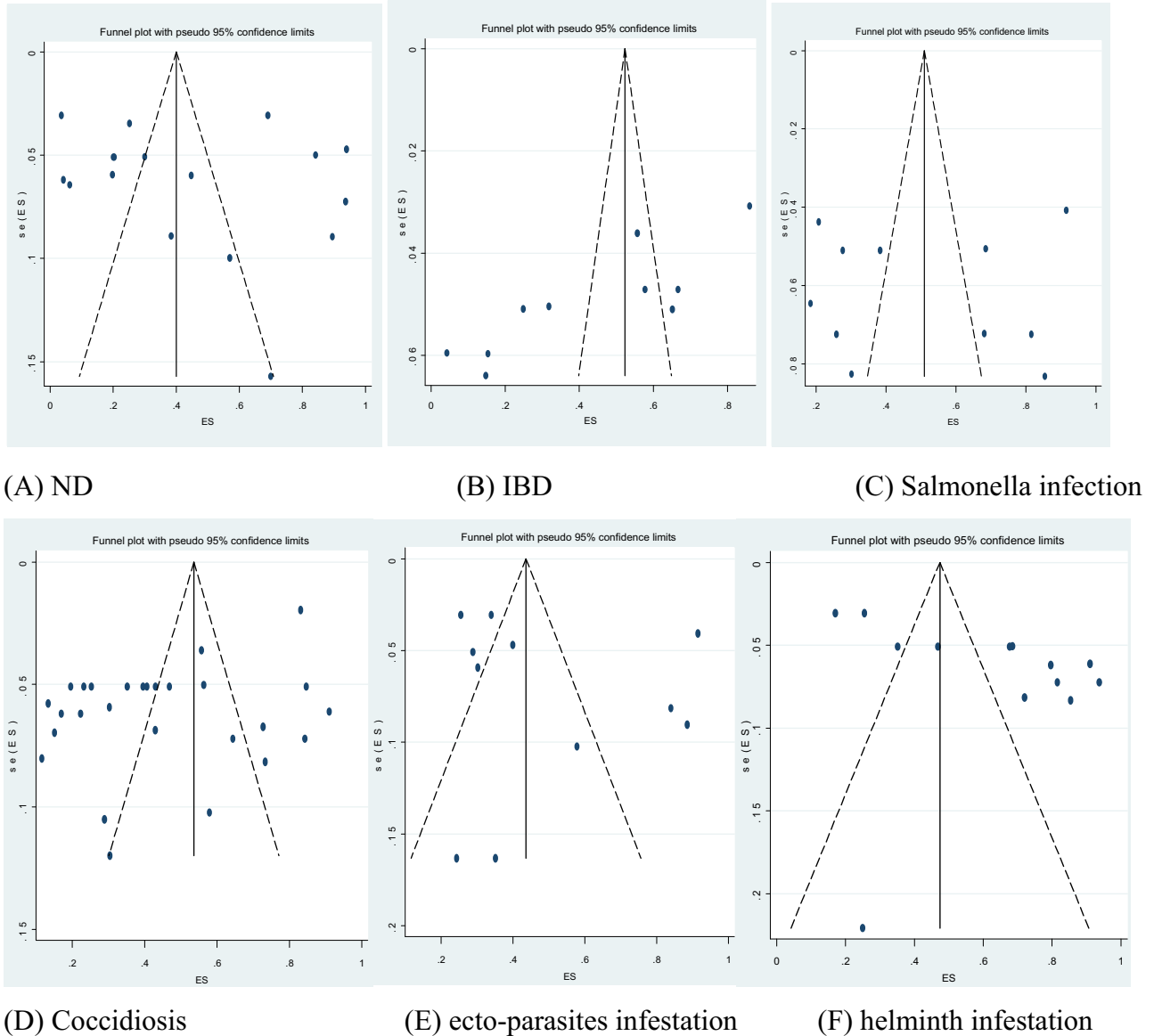


Figure 8. Funnel plots of the pooled prevalence estimates of a) ND, b) IBD, c) *Salmonella* infection, d) Coccidiosis, e) ecto-parasites infestation, f) helminth infestation.

0.001, respectively. Hence, the statistical significance of the P -values of both tests reported for both diseases shows that there is likelihood of publication bias (significant funnel plot asymmetry).

DISCUSSION

To the best of our knowledge, this is the first systematic review and meta-analysis work on infectious and parasitic diseases of poultry reporting pooled prevalence estimates and spatial and temporal distributions of these diseases in Ethiopia. The review included data of 110 studies which reported 16 different diseases and involved a total of 42,472 chickens/samples. The review indicates that there was very little research on infectious and parasitic diseases of poultry until about

2012 when a marked increase in prevalence studies was noted. Most of the studies were conducted in central Ethiopia, leaving major gaps in the literature regarding poultry diseases in other parts of the country. This is of particular concern as major investments have been made in the poultry sector to support its development and potential provision of food and nutrition security in Ethiopia. There is thus an urgent need to intensify poultry disease research to inform the design and implementation of surveillance and control programs. An increasing poultry population will alter disease transmission dynamics; data on presence and distribution of diseases are urgently needed to populate disease transmission models in support of intervention programs. A likely reason for the research focus on central Ethiopia, especially Oromia Regional State, is the fact that these areas are closer to many universities and research

institutes. However, extensive farming systems are currently the most dominant poultry production system countrywide; hence, research in this production system and in the different regions is needed.

The majority of the studies were published over 4 years (2012 to 2016). This lack of consistency and interruptions in conducting and reporting research on poultry diseases reflects the low and unsustainable poultry health research undertaken in the country to date. Despite the discrepancies and inconsistencies in poultry disease research over time, an overall increasing trend in the number of studies was noted starting from the year 2002. This increasing trend in the number of studies could be linked to the opening of several veterinary higher education and research institutions since 2003. Hence, the volume of scientific evidence has been growing over time and may indicate the impact of the diseases on the productivity and profitability of the poultry subsector and poultry-origin public health issues. The issue of poultry veterinary services requires the attention of poultry producers and industries, universities, and research institutes working at the regional, national, and international levels as well as local, regional, and federal governments. Although the quantity of poultry disease research increased over time, it was noted that the quality of research is generally low as more than 37 studies were ranked as low quality. In addition, with few exceptions, research appears to be conducted haphazardly or arbitrarily; teams of researchers dedicated to the study of the various aspects of a particular disease appear to be lacking. The low quality of research on poultry diseases in Ethiopia could be related to financial and infrastructure constraints; it may also be reflective of the need to prioritize poultry research in universities and research institutes. Encouraging graduate and doctoral students to undertake poultry disease research will contribute to the literature and support the national prioritization of the poultry subsector.

ND, IBD, avian coccidiosis, helminth infestation, ecto-parasite infestation, and *Salmonella* and *Campylobacter* infections were found to be the most important diseases of chickens in Ethiopia based on prevalence. These diseases, particularly the first 6 diseases, appear to have serious impacts on poultry productivity. For instance, Addis et al. (2014) reported that ND, IBD, and avian coccidiosis, in order of importance, were the major causes of chicken mortalities in Bahir Dar Zuria. Similarly, Alemu (1985) reported that ND, avian coccidiosis, and salmonellosis were major causes of mortalities in chickens kept under low management systems of Ethiopia. Moreover, Dessie (1996) reported that parasitism is among the most important causes of chicken losses. Dessie and Olge (2001) reported more than 61% of chicken mortality attributed to major poultry diseases. *Salmonella* and *Campylobacter* infections transmitted from chickens are of high public health importance. However, no detailed data were readily available to appropriately discern the impacts of the specific dis-

eases. Detailed socioeconomic and public health studies on poultry diseases are needed to support the poultry subsector in Ethiopia.

The high prevalence of poultry diseases in Ethiopia may be attributed to the low level of biosecurity, low vaccination coverage, unscientific poultry management practices, and almost absent poultry veterinary interventions across the country, particularly in the extensive poultry production system. Among the studied diseases, fowl cholera (68%), helminth infestation (62%), and *Salmonella* infections (51%) were reported to be the most prevalent chicken diseases in Ethiopia, followed by ecto-parasite infestation (50%).

The higher number of studies on avian coccidiosis could be due to the uncomplicated and less-costly detection methods of coccidian pathogens and the fact that diarrhea, which is the major clinical sign of avian coccidiosis, is most frequently reported by poultry producers. Further, the floor system is the dominant poultry housing system in Ethiopia, which is highly associated with a high prevalence of avian coccidiosis. In addition, avian coccidiosis is considered to be the most economically important disease in the country (Kinung'hi et al., 2004; Gebrewahd and Moges, 2016). Similarly, the reason for the high number of studies on ND is that this disease is recognized by poultry producers, veterinarians, and researchers for its higher morbidity and mortality. Currently, constraints exist with regard to the quality, accessibility, and coverage of ND vaccine in the country, which might have facilitated other work on the disease.

While no previous attempts have been made to pool prevalence of the most important diseases, the Central Statistical Authority (CSA) of Ethiopia (2017) estimated that 59.46% of Ethiopian chickens were afflicted with at least one of the diseases, which is broadly in line with the findings of this review. The higher pooled prevalence of some specific diseases is found to be comparable with the results of some available previous studies conducted elsewhere. For instance, Miguel et al. (2013) reported 67% (95% CI: 58 to 75) pooled prevalence of ND in eastern, western, and southern African countries including Ethiopia. Similarly, Tonouhewa et al. (2017) reported 37.4% (CI: 29.2 to 46.0%) pooled prevalence of *Toxoplasma gondii* in chickens in eastern, western, northern, and central African countries including Ethiopia. Outside of Africa, Shokri et al. (2017) reported 20% (95% CI: 3 to 38%) pooled prevalence of toxoplasmosis in chickens in Iran. Moreover, Pintar et al. (2015) reported 34% (2 to 78%) pooled prevalence of *Campylobacter* infection in animals. Apart from animals, Tadesse (2014) reported 8.22% (5.75 to 10.69%) pooled prevalence of human salmonellosis in diarrheic human patients in Ethiopia. The differences in the pooled prevalence could be due to variations in geographic location of the study areas, production systems, level of poultry farm biosecurity, and status of poultry health interventions.

The overall high pooled prevalence found could be due to the fact that poultry veterinary service in general, and infectious and parasitic disease prevention and control interventions in particular, are not adequately available in the country. In support of this, CSA (2017) reported that treatment coverage of diseased chickens in the country was only 26.53% and the rest of the diseased chicken population (about 73%) is believed to be untreated and eventually die. Hence, the higher nationwide pooled prevalence of those infectious and parasitic diseases indicates that the burden of those diseases on the productivity of chickens, profitability of poultry businesses, and socioeconomic returns of the subsector in Ethiopia is very impactful and economically significant. For instance, as per the report of CSA (2017), 56.5% of the total Ethiopian chicken population (i.e. about 60 million) die every year which is attributed to annual monetary losses of about ETB 3.6 billion (= about 120 million USD), assuming that the average market value of a chicken is ETB 100 birr.

Cochran's Q , I^2 , and τ^2 statistics indicated higher heterogeneity among studies reporting ND, IBD, coccidiosis, helminth infestation, ecto-parasite infestation, and *Salmonella* infection. Higgins and Green (2008) indicated that there are several possible sources of heterogeneity including clinical, methodological, and statistical, among studies that are included in meta-analyses. Methodological and clinical sources of heterogeneity contribute to the magnitude and presence of statistical heterogeneity. Significant statistical ($P < 0.05$) heterogeneity arising from methodological heterogeneity suggests that the studies are not all estimating the same effects due to different degrees of bias (Higgins and Green, 2008). In addition, Barendregt et al. (2013) suggested that heterogeneity is the main issue with meta-analysis of prevalence. They argued that when study results are heterogeneous, it cannot be assumed that the same phenomenon has been measured in a sufficiently similar way and that differences in results are due to sampling error only and hence, covariates could be looked at to explain heterogeneity. However, in studies on burden of disease, such as this study, the aim is to obtain a best estimate of prevalence, based on available data (Barendregt et al., 2013). Hence, considering the reported pooled prevalence as a measure of disease is valid. Nevertheless, the possible sources which might have led to the higher heterogeneity among studies could be due to variation in poultry breed types, disease diagnosis capacities and methods, management practices, variations over time, and production systems.

No publication bias was reported for studies on ND, coccidiosis, ecto-parasite infestations, and *Salmonella* infection. The possible reasons for this may be the fact that a sufficient number of studies were published and reviewed, or some articles might not have been published.

To conclude, this study contributes to the body of scientific knowledge that high-pooled prevalences of

infectious and parasitic diseases of poultry are present in Ethiopia. This evidence is particularly useful for policymakers, poultry producers, and other beneficiaries, and can help to inform the development of strategically sound poultry health interventions to control and prevent diseases from now onwards. However, most of the studies were conducted in central Ethiopia; poultry disease research across Ethiopia has been low and there is a major information gap for other parts of the country. It is also noted that the volume of research and evidence for central Ethiopia are not yet sufficient either. Hence, the highly prevalent and commonly studied diseases require immediate attention by the government and poultry producers to put them under control by devising robust disease prevention and control interventions which need to be strategically implemented across the country. Here, it can be suggested that deployment of vibrant private poultry health service providers at least in the major cities and towns of Ethiopia where more poultry businesses are flourishing seems very strategic option to address the studied prevalent diseases. Most importantly, given the growing importance of poultry in Ethiopia, there is an urgent need to support poultry health research in smallholders and intensifying production systems where significant poultry health research, considering the under-researched regions and areas of the country, is urgently needed.

SUPPLEMENTARY DATA

Supplementary data are available at *Poultry Science* online.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest related to the preparation and publication of this paper.

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