The role of feeds in the transmission of chicken pathogens in Dodoma Urban District, Tanzania

Rosemary Peter Mramba [1]

Department of Biology, The University of Dodoma, Dodoma, Tanzania

ABSTRACT Chicken production is an important economic activity in Tanzania. Indigenous chickens are kept in rural areas, while exotic breeds are kept in urban areas. Due to their high productivity, exotic breeds are becoming important sources of protein in fast-growing cities. Dodoma is one of the cities growing very fast in Tanzania. As a result, production of layers and broilers has increased dramatically. However, diseases remain the major challenge to chicken production despite the efforts of livestock officers to educate people on good management practices. This has made farmers think that feeds may be the source of pathogens. The study's objectives were thus to identify the major diseases affecting broiler and layer chickens in the Dodoma urban district, as well as the potential role of feeds in pathogen transmission to chickens. A household survey was conducted to identify common diseases affecting chickens in the study area. Thereafter, locally prepared feed samples were collected from twenty shops available in the district to determine the presence of *Salmonella* and *Eimeria* parasites. The presence of *Eimeria* parasites in the feeds was determined by raising day-old chicks in a sterile environment for 3 wk while feeding them the feed samples collected. Fecal samples from the chicks were analyzed for the presence of *Eimeria* parasites. *Salmonella* contamination of the feed samples was determined in the laboratory through the culture method. The study found that coccidiosis, Newcastle disease, fowl typhoid, infectious bursal disease, and colibacillosis are the main diseases affecting chickens in the district. After 3 wk of rearing, 3 out of 15 chicks developed coccidiosis. In addition, about 31.1% of the feed samples showed the presence of *Salmonella* spp. The prevalence of *Salmonella* was highest in limestone (53.3%), followed by fishmeal (26.7%), and maize bran (13.3%). It has been concluded that feeds are potential carriers of pathogens. To reduce economic losses and the continuous use of drugs in chicken production, health authorities should assess the microbial quality of poultry feeds.

Key words: chicken, disease, *Eimeria* spp., feed, *Salmonella* spp

2023 Poultry Science 102:102558
https://doi.org/10.1016/j.psj.2023.102558

INTRODUCTION

Chicken production in Tanzania plays an important role in human nutrition, income generation, and improving the livelihoods of people (Andrew et al., 2019; Ngongolo et al., 2021). Tanzania has about 38.2 million local and 36.6 million exotic breeds of chicken (Magonka et al., 2016). Local chicken breeds are kept by farmers in rural areas, while improved and exotic breeds are commonly kept in urban areas (Magonka et al., 2016; Saleque et al., 2016). However, the level of protein-energy undernutrition and poverty is still high, especially in rural areas, calling for an increase in chicken production (Pius et al., 2021). In addition, climatic changes are expected to affect the production of large herbivores like cattle because pasture and forage production depend on climate (Henry et al., 2018; Godde et al., 2021). As a result, chickens, particularly the indigenous breeds, are regarded as the best alternative livestock because they are easy to manage by everyone in the household and produce high-quality protein (Charles et al., 2013; Desta, 2021; Pius et al., 2021). Improvements in chicken production, including the introduction of new strains, have been observed in many regions of Tanzania (Andrew et al., 2019; Maunde et al., 2021). However, these efforts are hindered by many factors, including chicken diseases (Ngongolo and Chota, 2021, 2022; Wilson et al., 2022).

The poultry sector in Tanzania is characterized by a high prevalence of diseases affecting small-scale producers, particularly Newcastle disease, salmonellosis, and coccidiosis (Chota et al., 2021; Ngongolo and Chota, 2022). This situation is exacerbated by low-

Received December 1, 2022.
Accepted January 30, 2023.

[1]Corresponding author: mramba2008@yahoo.com

quality vaccines, an unreliable cold chain supply of vaccines, as well as poor housing and sanitation conditions (Minga et al., 2001; Sambo et al., 2015; Saidi et al., 2020). Numerous initiatives, such as community education and vaccination, have been implemented to reduce the impact of diseases (Msoffe et al., 2010; Mbyuzi et al., 2012; Lindahl et al., 2019; Kalloka et al., 2021). Despite these efforts, the prevalence of chicken diseases remains high in the country (Sindiyo and Missanga, 2017; Chota et al., 2021; Ngongolo and Chota, 2021). As a result, chicken keepers now view some feed ingredients, like fishmeal, as potential sources of contamination.

Animal feeds may become contaminated with pathogens during harvesting, transportation, processing, and storage (Fedorka-Cray et al., 1997; Maciorowski et al., 2006). Disease pathogens have been isolated in commercial chicken feeds around the world (Jones and Richardson, 2004; Mdemu et al., 2016, 2017; Munoz et al., 2021; Ngai et al., 2021). The most common bacterial pathogens found in animal feeds are *Salmonella* species (Jones and Richardson, 2004; Mdemu et al., 2016; Munoz et al., 2021; Ngai et al., 2021) and *Escherichia coli* (Munoz et al., 2021; Ngai et al., 2021). However, there is little information on the presence of protozoan pathogens in animal feeds, such as *Eimeria* spp., most likely due to the difficulty of growing protozoa in culture medium (Visvesvara and Garcia, 2002). Feeds are formulated to meet nutritional requirements for chickens by using material from plants, animals, and mineral and vitamin sources. These ingredients may have different levels of contamination from pathogens due to the source, preparation, and storage methods. For example, fishmeal is regarded as the most contaminated feed component due to its high nutrient and spoilage rates (Skowron et al., 2014; Han et al., 2019). However, other components, such as maize bran and grains, are dried in open spaces where roaming animals such as dogs, chickens, and goats pass and drop feces.

Chicken production is a significant economic activity in the Dodoma region (Ngongolo and Chota, 2021; Ngongolo et al., 2021). While exotic breeds of chicken are frequently kept in urban areas, local breeds are typically kept in rural areas (Ngongolo and Chota, 2021). Recent population growth in the region due to the shifting of government headquarters from Dar es Salaam to the region has increased the need for more exotic breeds with higher productivity (Jackson, 2020). Exotic breeds are, however, more susceptible to diseases and parasites than local breeds (Msoffe et al., 2002; Ajayi, 2010; Mpenda et al., 2019; Manyelo et al., 2020). As a result, effective disease control is critical for the region's expansion of exotic breed chicken production. On the other hand, effective control measures for infectious disease require identification of the possible sources of the disease causing-agent. As a result, the purpose of this research was to determine the role of locally prepared chicken feeds in the transmission of *Salmonella* and *Eimeria* pathogens in chickens. These are among the diseases that cause great losses of chicken in the Dodoma region (Ngongolo and Chota, 2022). The majority of small-scale chicken keepers cannot afford commercial feeds made in sterile conditions due to their high prices (Mbwambo et al., 2016; Wilson et al., 2021). Instead, they rely on locally produced feeds, which are likely made in an unhygienic setting and may be contaminated with various pathogens. This jeopardizes the overall effectiveness of the control of pathogens, and thus diseases continue to increase in the region.

MATERIALS AND METHODS

Study Area

The study was conducted in the Dodoma Urban District in the Dodoma region. Dodoma is a semi-arid region with erratic and seasonal rains. The Dodoma urban district is part of Dodoma City, which has a population of 410,956 people, according to the 2012 census (Tanzania URT, 2013). The climate is characterized by a long dry season and erratic rains that fall in a single rainy season between November and April, with a mean annual rainfall of about 550 mm (Godfray and Tembo, 2022). The average maximum and minimum temperatures are 31°C and 18°C, respectively (Shemsanga et al., 2017). Livestock production and farming are the major economic activities of the local people of the Dodoma region (Bundala et al., 2020). Dodoma is one of the regions with the highest density of chickens in Tanzania, including both indigenous and exotic breeds (Ngongolo and Chota, 2021; Ngongolo et al., 2021). Although indigenous breeds of chicken are more preferred by consumers than exotic breeds, their productivity is very low (Padhi, 2016; Wilson et al., 2022). Thus, the indigenous breeds cannot meet the demand for protein in big cities, necessitating an increase in the production of exotic breeds in urban areas.

Data Collection and Laboratory Analysis

Household Survey. A household survey was conducted in March 2022 to identify the common diseases affecting chickens (broilers and layers) in Dodoma Urban District. Four wards, namely Chang'ombe, Kikuyu Kaskazini, Kikuyu Kusini, and Nzuguni, were selected randomly for this study. The number of households in each ward that keep broilers and chickens was determined with the assistance of local leaders. A sample of 92 households was drawn from the 119 households that keep broilers and layers in the district. Sample determination was based on the Yamane's formula which is given as: $n = \frac{N}{1+N(e^2)}$ where n is the sample size, N is the study population, and e is the sample error (Naing, 2003). A sample error of 5% was used in this study.

Structured interviews were conducted to collect information from randomly selected households in each ward. The information gathered covered chicken breed, rearing methods, diseases that affect the chickens, and their views on feeds as a source of chicken pathogens.

Clinical observation of sick chickens in each household was done, and the possible cause of the diseases was determined based on clinical signs. The survey followed strict confidentiality guidelines and required participants to provide informed consent.

Determination of Eimeria Pathogens in Chicken Feed. Locally prepared feeds are sold in small shops where different components are sold separately. A total of 20 feed shops were identified in the district. Feed samples were bought from all the shops, making 20 samples of each feed component (maize bran, fish meal, and lime). The sample collection was done in April and May 2022. The feed samples were put in sterile ziplock bags and sent to the Tanzania Veterinary Laboratory Agency (**TVLA**) in Dodoma. Observation of oocysts under a microscope is difficult because contamination can be low and thus missed. To overcome this challenge, the feed ingredients from all shops were mixed and used to raise day-old Kuroiler chicks for 3 wk in a sterile laboratory environment at TVLA. Kuroiler is an improved dual-purpose breed of chicken reared for both meat and egg production. The feed components were formulated to meet the nutritional requirements for chicks. All equipment was disinfected, and drinking water was boiled to control other sources of infection. The chicks were raised in separate compartments in the laboratory. The chicks were observed closely for any signs of disease. The chick's feces were sampled twice a week, and the presence of *Eimeria* oocysts was determined using the fecal flotation test.

Isolation of Salmonella From the Feed Samples. Samples of maize bran, fishmeal, and limestone were sent to the laboratory at the College of Natural and Mathematical Sciences at the University of Dodoma for determination of the presence of *Salmonella* sp. About 25 g of each feed component was pre-enriched in 225 mL of buffered peptone water (Himedia, Mumbai, India) and incubated at 37°C for 24 h. Thereafter, 0.1 mL of the pre-enrichment culture was added to 10 mL of Rappaport-Vassiliadis broth (Himedia, Mumbai, India) and incubated at 41.5°C for 24 h. Xylose-Lysine-Deoxycholate Agar (**XLD-Agar**, Scharlau Chemie S.A., Barcelona Spain) was used as a selective and differential culture medium. Loopful inoculums of each sample were streaked into petri dishes containing the prepared medium and incubated for 24 h at 37°C to obtain single types of colonies. The colonies were identified as *Salmonella* species based on the colony appearance, Gram stain, and triple-sugar-iron reaction. The microbial cultivation produced data on the presence or absence of *Salmonella* growth as well as the number of *Salmonella* colonies. Ethical clearance for undertaking this study with reference number MA.84/261/02 was granted by the University of Dodoma.

Statistical Analysis

The frequency of diseases identified by the farmers and through observation of sick chickens during the household survey was determined. The Pearson's chi-square (χ^2) test at a significance level of 5% was used to determine the association between the frequency of the disease and chicken breeds (layers and broilers). Pearson's chi-square is used to test associations between categorical variables when observations of all groups that are compared are not less than 5 (McHugh, 2013). Furthermore, the prevalence of *Salmonella* contamination in the feed samples was calculated as a percentage of the positive samples. Then, a chi-square test was used to determine the relationship between the prevalence of *Salmonella* contamination among different feed components. A zero-inflated Poisson regression was used to compare the number of *Salmonella* colonies between the samples of the feed components. The prevalence of *Eimeria* contamination in the feeds was calculated as a percentage of chicks that developed coccidiosis. The statistical analyses were done in R version 4.2.0, while figures were created in Excel.

RESULTS

Farmers Survey

A total of 92 farmers were visited, of whom 28 were from Chang'ombe, 26 from Kikuyu Kaskazini, 24 from Kikuyu Kusini, and 14 from Nzuguni. Out of the 92 farmers visited, 52 kept broilers and 40 kept layers. Seventy-two farmers used the ground-housing system, while twenty farmers used the cage-housing system. Fifteen farmers (75%) who used a cage system thought feeds might be a source of disease pathogens, while eleven farmers (15%) who used a ground-housing system blamed feeds as the source of disease pathogens. The chicken diseases identified by the farmers were coccidiosis, Newcastle, Infectious Bursal Disease (**IBD**), fowl typhoid, fowl pox, and colibacillosis. About 52% of the farmers named coccidiosis as the most important chicken disease, while 43% named Newcastle disease as the most important chicken disease. Furthermore, 41% of the farmers named coccidiosis as the second most important disease, 34% named IBD as the second most important disease, and 13% classified fowl typhoid as the second most important disease. Further details of the diseases identified by the farmers are shown in Figure 1. The observation of clinical signs of sick chicken among the farmers showed that coccidiosis, fowl typhoid, IBD, and colibacillosis were the most common diseases causing chicken sickness (Figure 2). Except for colibacillosis, which was more important in layers than broilers ($\chi^2_{(1,\ N\ =\ 14)} = 8.161$, $P = 0.004$), all other diseases were equally important in broilers and layers ($P > 0.05$).

Prevalence of Coccidiosis in Chicks

The prevalence of coccidiosis was 20% ($N = 15$) after the chicks were raised in a sterile environment for 3 wk. One chick developed brownish diarrhea in the second week, and 2 in the third week. A fecal flotation test

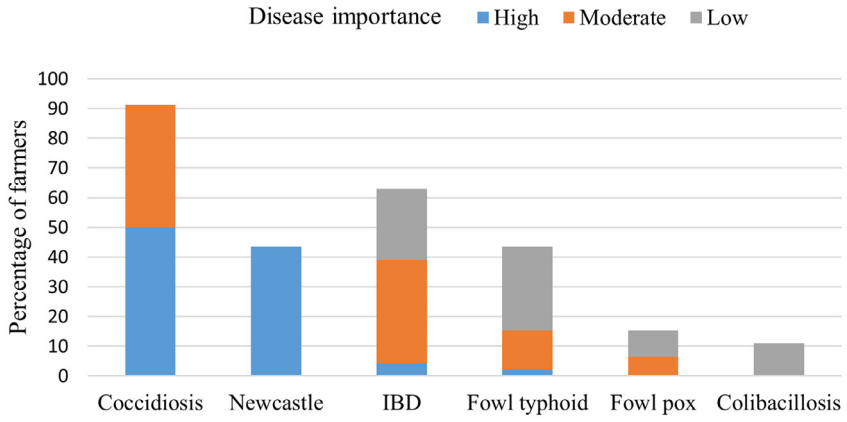

Figure 1. Chicken diseases identified by farmers in the study area.

revealed that the sick chicks' feces contained *Eimeria* oocysts. Because the environment was sterile, it is likely that the chick got the *Eimeria* oocysts from the feeds.

Prevalence of Salmonella Parasites in the Feed Samples

The overall prevalence of *Salmonella* pathogens in the feeds was 31.1%. The prevalence differed between the feed components. The prevalence was 53.3% in limestone, 26.7% in fishmeal, and 13.3% in maize bran (Figure 3). The difference in *Salmonella* prevalence between the feed components was statistically significant ($\chi^2_{(2,\ N\ =\ 20)} = 5.806$, $P = 0.024$). The number of *Salmonella* colonies had a significant positive association with maize bran and limestone (Table 1). The mean number of colonies in maize bran was 3.01 higher than in fishmeal, and 2.18 higher in limestone than in fishmeal.

DISCUSSION

According to the findings, feeds can be a source of pathogens for chickens, such as *Salmonella* and *Eimeria* species. *Salmonell*a was most prevalent in limestone, where more than half of the samples tested positive. Furthermore, within the first 3 wk of life, 20% of chicks reared in sterile conditions developed coccidiosis. Feeds were most likely the source of the infection because the environment was sterile. Unhygienic conditions for drying and storing the feeds may have contributed to feed contamination.

Prevalence of Chicken Diseases in Households

The study shows that diseases are one of the major challenges of chicken production in Dodoma Urban District. These findings are consistent with previous research in the region (Ngongolo and Chota, 2022) and elsewhere in the country (Mbyuzi et al., 2012; Swai et al., 2013; Sindiyo and Missanga, 2017). Coccidiosis infections, fowl typhoid, IBD, and colibacillosis were the main diseases identified based on the clinical signs of sick chickens. Coccidiosis and fowl typhoid are transmitted from animal to animal through contact with infected feces or ingestion of infected feeds, so unhygienic conditions increase the prevalence. Furthermore, fowl typhoid can be passed from hen to chick via eggs, making it more difficult to control (Berhanu and Fulasa, 2020). IBD is a highly contagious viral disease of young chickens (Rukia et al., 2020). IBD can be effectively controlled through vaccination (Rukia et al., 2020); thus, high prevalence indicate a lack of or ineffective vaccination. High prevalence of these diseases have been reported in

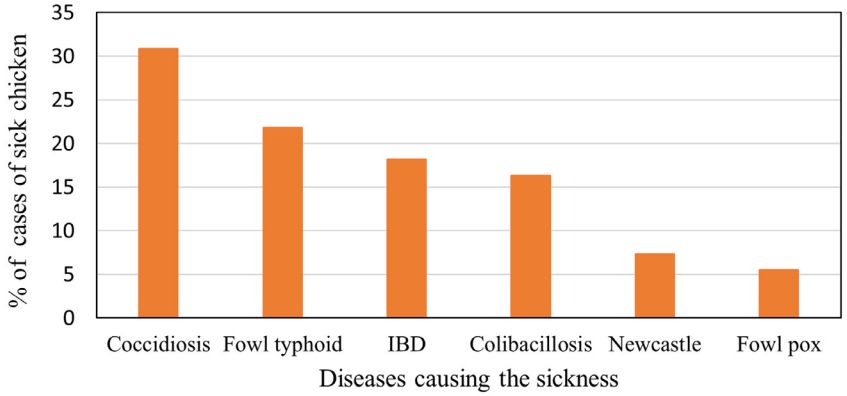

Figure 2. Chicken diseases identified based on the observation of clinical signs of sick chickens ($n = 79$ chickens).

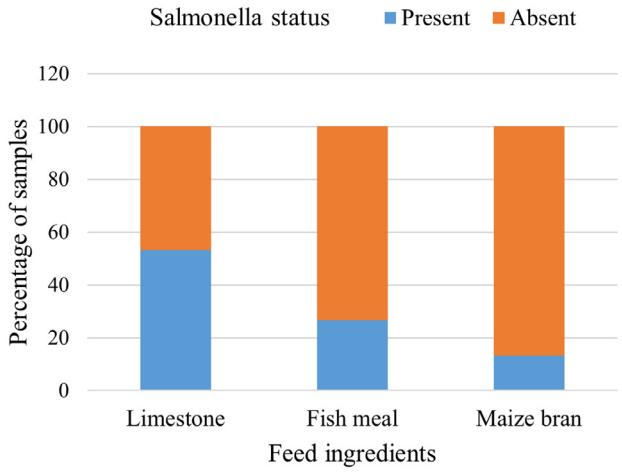

Figure 3. The percent of samples of the 3 feed ingredients that had *Salmonella* colonies.

other layer and broiler studies (Swai et al., 2013; Shepelo and Maingi, 2014; Ngongolo and Chota, 2022). Based on the farmer's views, coccidiosis, Newcastle disease, IBD, and fowl typhoid were the main diseases affecting chicken production. This finding is consistent with the study by Ngongolo and Chota (2022) in the region, although their study involved both exotic and indigenous breeds of chicken. The Newcastle disease is common in endogenous chickens that are kept in a free-ranging system without vaccination or biosecurity measures (Yongolo et al., 2011; Simbizi et al., 2021; Mngumi et al., 2022). The incidence is expected to be low in broiler and layer production, where vaccination is more practiced. However, because Newcastle disease is most prevalent in indigenous chickens, many people tend to relate any chicken sickness to Newcastle disease.

Prevalence of Coccidiosis in the Chicks

Coccidiosis is a dreadful parasitic disease that causes great economic loss in the poultry industry (Blake et al., 2020). It is caused by *Eimeria* species of the phylum Apicomplexa. *Eimeria* oocysts are the main cause of coccidiosis, which is contracted by consuming contaminated food, water, and litter (Fatoba and Adeleke, 2018). *Eimeria* oocysts have a thick wall that is resistant to both mechanical and chemical damage, allowing them to survive in the environment for a long time (Fatoba and Adeleke, 2018). The oocysts require moisture, oxygen, and warmth to sporulate (Makau et al., 2017). As a result, the moist storage conditions of locally prepared feeds, combined with the warm climate of tropical countries, create a favorable environment for sporulation. In this study, 3 out of 15 chicks developed coccidiosis within 3 wk of life. This shows that the chicken ingested infective oocysts from the feed. Young chickens with immature immune systems are more vulnerable to *Eimeria* parasites (Abebe and Gugsa, 2018). Despite the importance of coccidiosis in livestock production, there have been few studies on the contamination of animal feeds with *Eimeria* parasites. A study by Kiani et al. (2007) found a prevalence of 17% of *Eimeria* oocysts in broiler feeds, indicating that feeds are potential sources of coccidiosis in chickens.

Table 1. Zero-inflated Poisson regression predicting the number of colonies from fishmeal, maize bran, and limestone.

Count model coefficients (Poisson with log link)					
Response variable	Predictors	Estimate	SE	*z* value	*P* value
Number of colonies	Intercept	1.296	0.272	4.767	<0.001
	Limestone	0.784	0.299	2.619	0.008
	Maize bran	1.102	0.345	3.192	0.001
Zero-inflation model coefficients (binomial with logit link)					
	Predictors	Estimate	SE	*z* value	*P* value
	Intercept	2.156	0.591	2.852	0.014
	Limestone	−1.109	0.785	−1.963	0.015
	Maize bran	1.896	0.622	1.931	0.035

Fishmeal is part of the intercept.

Prevalence of Salmonella Parasites in the Feed Samples

The overall prevalence of *Salmonella* in the feeds was 33.11%, which is greater than the 29% reported by Mdemu et al. (2016) in commercial chicken feeds in Tanzania and the 28% in Kenya (Ngai et al., 2021), but lower than the 71.43% reported in Bangladesh (Chowdhury et al., 2011). Studies in Nigeria have reported a varying degree of *Salmonella* contamination in chicken feeds, for example, 38% (Matthew et al., 2017), 37.5% (Omololu and Bamidele, 2017), and in feeds of different age groups of chicken (Okoli et al., 2006). However, the majority of these studies are based on commercial feeds, so implementing feed mill biosecurity can prevent contamination (Huss et al., 2018). This study is based on locally prepared feeds that are directly collected from producers in rural areas without any processing or biosecurity measures. The feeds are sold in small shops with poor facilities and storage conditions. Because the majority of the small-scale chicken keepers depend on the locally prepared feeds, regulations should be put in place to ensure that biosecurity precautions will be followed.

A complete animal feed is made up of a variety of raw materials to ensure the balance of the necessary nutrients. The feed ingredient used may have a different level of contamination depending on the source and production methods (Furuta et al., 1980; Jones and Richardson, 2004; Udhayavel et al., 2017). In this study, the prevalence of *Salmonella* contamination was highest in limestone at about 53%, followed by fish meal at 26.7%. Given that limestone is made from soil materials found in quarries or underground mines, the higher prevalence is likely related to soil contamination. These areas can be easily contaminated by different pathogenic organisms from animal feces and waste water. Moreover, there are no clear procedures for limestone processing, particularly sterilization, before it is supplied for the formulation of animals feeds. Elsewhere, fecal and soil contamination have been linked to pathogen incidences in

animal feeds (Wojdat et al., 2006), which support the high prevalence of limestone contamination. A related study by Jones and Richardson (2004) found high levels of *Salmonella* contamination in cotton seed meal, fish meal, and soybean meal. On the other hand, Udhayavel et al. (2017) found high levels of contamination in fish meal, followed by bone meal, meat and bone meal, and dry fish. Because of their high protein content, animal sources of feed ingredients such as fish meal, meat meal, and bone meal have been linked to increased pathogen incidences (Furuta et al., 1980; Udhayavel et al., 2017). However, the number of colonies was higher in maize bran despite having fewer incidences of contamination. Maize bran is normally dried in open space, where it is more likely to be visited by roaming animals that deposit feces while feeding.

Since it is difficult to eliminate pathogens present in raw feeds once they are contaminated (Huss et al., 2018), precautions should be taken to prevent disease development in animals. Feed additives have been implemented in different countries to control *Salmonella* and *Eimeria* parasites (Van Immerseel et al., 2002; Meunier et al., 2016; Leiva et al., 2019). However, the implementation may be difficult for locally produced feeds as there are no measures for controlling the quality of the feeds. In addition, continuous use of antibiotics and other drugs to treat chicken diseases has impacts on human health (Mund et al., 2017; Ulomi et al., 2022). Thus, implementation of sanitary measures will reduce the occurrence of diseases and the use of drugs in chicken production.

CONCLUSIONS

The study found that poultry feed harbors *Salmonella* and *Eimeria* parasites. The level of contamination differs between feed ingredients, with a high prevalence in limestone followed by fishmeal. Contaminated feeds increase disease incidences, resulting in economic losses and a public health risk due to the continued use of drugs to treat sick chickens. Thus, authorities should assess the microbial quality of poultry feeds to ensure feed safety. Further studies on the mechanisms of feed contamination and control measures are recommended.

ACKNOWLEDGMENTS

I would like to thank livestock officers and field assistants at the Dodoma Urban District who provided technical support during the data collection process. I thank the chicken keepers in Dodoma Urban District for participating in the household survey. I am grateful to the Tanzania Veterinary Laboratory Agency (Dodoma) for allowing me to use their laboratory for chick raising and fecal sample analysis.

DISCLOSURES

The author declares that there are no financial or personal interests to disclose.

REFERENCES

Abebe, E., and G. Gugsa. 2018. A review on poultry coccidiosis. Abyssinia J. Sci. 3:1–12.

Ajayi, F. 2010. Nigerian indigenous chicken: a valuable genetic resource for meat and egg production. Asian J. Poult. Sci. 4:164–172.

Andrew, R., J. Makindara, S. H. Mbaga, and R. Alphonce. 2019. Economic viability of newly introduced chicken strains at village level in Tanzania: FARMSIM model simulation approach. Agric. Syst. 176:102655.

Berhanu, G., and A. Fulasa. 2020. Pullorum disease and fowl typhoid in poultry: a review. Br. J. Poult. Sci 9:48–56.

Blake, D. P., J. Knox, B. Dehaeck, B. Huntington, T. Rathinam, V. Ravipati, S. Ayoade, W. Gilbert, A. O. Adebambo, and I. D. Jatau. 2020. Re-calculating the cost of coccidiosis in chickens. Vet. Res. 51:1–14.

Bundala, N., J. Kinabo, T. Jumbe, C. Rybak, and S. Sieber. 2020. Does homestead livestock production and ownership contribute to consumption of animal source foods? A pre-intervention assessment of rural farming communities in Tanzania. Sci. Afr. 7: e00252.

Charles, R. L., P. K. T. Munishi, and E. F. Nzunda. 2013. Agroforestry as adaptation strategy under climate change in Mwanga District, Kilimanjaro, Tanzania. J. Environ. Prot. 3:29–38.

Chota, A., O. Kitojo, and K. Ngongolo. 2021. Knowledge on diseases, practices, and threats of drugs residues in chicken food chains in selected districts of Dodoma region, Tanzania. J. Appl. Poult. Res. 30:100186.

Chowdhury, A., A. Iqbal, M. Uddin, and M. Uddin. 2011. Study on isolation and identification of Salmonella and Escherichia coli from different poultry feeds of Savar Region of Dhaka, Bangladesh. J. Sci. Res. 3:403–411.

Desta, T. T. 2021. Sustainable intensification of indigenous village chicken production system: matching the genotype with the environment. Trop. Anim. Health Prod. 53:1–14.

Fatoba, A. J., and M. A. Adeleke. 2018. Diagnosis and control of chicken coccidiosis: a recent update. J. Parasit. Dis. 42:483–493.

Fedorka-Cray, P. J., A. Hogg, J. T. Gray, K. Lorenzen, J. Velasquez, and P. Von Behren. 1997. Feed and feed trucks as sources of *Salmonella* contamination in swine. J. Swine Health Prod. 5:189–193.

Furuta, K., S. Morimoto, and S. Sato. 1980. Bacterial contamination in feed ingredients, formulated chicken feed and reduction of viable bacteria by pelleting. Lab. Anim. 14:221–224.

Godde, C., D. Mason-D'Croz, D. Mayberry, P. K. Thornton, and M. Herrero. 2021. Impacts of climate change on the livestock food supply chain; a review of the evidence. Glob. Food Sec. 28:100488.

Godfray, G., and M. M. Tembo. 2022. Assessment of ground water potentiality in semi-arid area of central Tanzania. Implication from geology and geomorphology of the Dodoman supergroup. Geol. Ecol. Landsc. 1–20.

Han, Y., J. Wang, Z. Zhao, J. Chen, H. Lu, and G. Liu. 2019. Detecting antibiotic resistance genes and human potential pathogenic bacteria in fishmeal by culture-independent method. Environ. Sci. Pollut. Res. 26:8665–8674.

Henry, B., R. Eckard, and K. Beauchemin. 2018. Adaptation of ruminant livestock production systems to climate changes. Animal 12 s445-s456.

Huss, A., R. Cochrane, C. Jones, and G. G. Atungulu. 2018. Physical and chemical methods for the reduction of biological hazards in animal feeds. Pages 83−95 in Food and Feed Safety Systems and Analysis. P. Ricke, ed. Academic Press, Cambridge, MA.

Jackson, W. 2020. Economic analysis of small-scale poultry production in Dodoma region: a case of Chawakubodo cooperative society. The University of Dodoma, Dodoma, Tanzania MA Diss.

Jones, F., and K. Richardson. 2004. *Salmonella* in commercially manufactured feeds. Poult. Sci. 83:384–391.

Kalloka, M., W. Maulaga, S. Komba, E. Kileo, E. Rukambile, B. Bagnol, and R. Alders. 2021. Interdisciplinary approach to combat food and nutrition insecurity in rural resource-poor settings of Central Tanzania. Tanzan. J. Agric. Sci. 20:138–145.

Kiani, R., M. Rasadi, and M. N. Mohammadian. 2007. Sources and routes of introduction of *Eimeria* oocysts into broiler chick's houses. Int. J. Poult. Sci. 6:925–927.

Leiva, A., A. Molina, M. Redondo-Solano, G. Artavia, L. Rojas-Bogantes, and F. Granados-Chinchilla. 2019. Pet food quality assurance and safety and quality assurance survey within the Costa Rican pet food industry. Animals 9:980.

Lindahl, J. F., J. Young, A. Wyatt, M. Young, R. Alders, B. Bagnol, A. Kibaya, and D. Grace. 2019. Do vaccination interventions have effects? A study on how poultry vaccination interventions change smallholder farmer knowledge, attitudes, and practice in villages in Kenya and Tanzania. Trop. Anim. Health Prod. 51:213–220.

Maciorowski, K. G., P. Herrera, M. M. Kundinger, and S. C. Ricke. 2006. Animal feed production and contamination by foodborne Salmonella. J. Verbrauch. Lebensm. 1:197–209.

Magonka, J., D. Sendalo, E. Goromela, P. Malingila, and E. Daniel. 2016. Production performance of indigenous chicken under semi intensive management conditions in Central Tanzania. Huria 22:73–80.

Makau, D. N., G. K. Gitau, G. K. Muchemi, L. F. Thomas, E. A. J. Cook, N. A. Wardrop, E. M. Fèvre, and W. A. de Glanville. 2017. Environmental predictors of bovine Eimeria infection in western Kenya. Trop. Anim. Health Prod. 49:409–416.

Manyelo, T. G., L. Selaledi, Z. M. Hassan, and M. Mabelebele. 2020. Local chicken breeds of Africa: their description, uses and conservation methods. Animals 10:2257.

Matthew, O., R. Chiamaka, and O. Chidinma. 2017. Microbial analysis of poultry feeds produced in Songhai farms, Rivers State, Nigeria. J. Microbiol. Exp. 4:00110.

Maunde, R., J. Lyimo-Macha, and J. Jeckoniah. 2021. The contribution of improved chicken strains in promoting women empowerment in Bariadi and Muheza Districts, Tanzania. Tanzan. J. Agric. Sci. 20:94–100.

Mbwambo, N., S. Nandonde, and C. Ndomba. 2016. Assessment of animal feed resources in Tanzania. Nairobi, Kenya: Assessment of animal feed resources in Tanzania. Tanzania Ministry of Agriculture, Livestock and Fisheries and International Livestock Research Institute (ILRI, Nairobi, Kenya.

Mbyuzi, A., E. Komba, and R. Mulangila. 2012. Integrating interventions against village chicken diseases to reduce mortalities of chicks and growers in southern zone, Tanzania. Livest. Res. Rural Dev. 24:23.

McHugh, M. L. 2013. The chi-square test of independence. Biochem. Med. 23:143–149.

Mdemu, S., J. Mathara, and Z. Makondo. 2017. Antibiotic resistance of *Salmonella* isolated from commercial chicken feeds in Dar es Salaam, Tanzania. Tanzan. Vet. J. 35:63–69.

Mdemu, S., J. M. Mathara, and Z. E. Makondo. 2016. Isolation of *Salmonella* in commercial chicken feeds in Ilala district. Am. Sci. Res. J. Eng. Technol. Sci. 19:1–8.

Meunier, M., M. Guyard-Nicodème, D. Dory, and M. Chemaly. 2016. Control strategies against C ampylobacter at the poultry production level: biosecurity measures, feed additives and vaccination. J. Appl. Microbiol. 120:1139–1173.

Minga, U., M. M. A. Mtambo, A. M. Katule, S. K. Mutayoba, N. A. Mwalusanya, P. Lawrence, R. H. Mdegela, and J. E. Olsen. 2001. Improving the health and productivity of the rural chicken in Africa: research and development efforts in Tanzania. Proceedings of the SADC Planning Workshop on Newcastle Disease Control in Village Chickens, ACIAR.

Mngumi, E. B., F. N. Mpenda, and J. Buza. 2022. Epidemiology of Newcastle disease in poultry in Africa: systematic review and meta-analysis. Trop. Anim. Health Prod. 54:1–12.

Mpenda, F., M. Schilling, Z. Campbell, E. Mngumi, and J. Buza. 2019. The genetic diversity of local African chickens: a potential for selection of chickens resistant to viral infections. J. Appl. Poult. Res. 28:1–12.

Msoffe, P. L. M., D. Bunn, A. P. Muhairwa, M. M. A. Mtambo, H. Mwamhehe, A. Msago, M. R. S. Mlozi, and C. J. Cardona. 2010. Implementing poultry vaccination and biosecurity at the village level in Tanzania: a social strategy to promote health in free-range poultry populations. Trop. Anim. Health Prod. 42:253–263.

Msoffe, P. L. M., M. M. A. Mtambo, U. M. Minga, P. S. Gwakisa, R. H. Mdegela, and J. Olsen. 2002. Productivity and natural disease resistance potential of free-ranging local chicken ecotypes in Tanzania. Livest. Res. Rural. Dev. 14.

Mund, M. D., U. H. Khan, U. Tahir, B.-E. Mustafa, and A. Fayyaz. 2017. Antimicrobial drug residues in poultry products and implications on public health: a review. Int. J. Food Prop. 20:1433–1446.

Munoz, L. R., W. J. Pacheco, R. Hauck, and K. S. Macklin. 2021. Evaluation of commercially manufactured animal feeds to determine presence of *Salmonella, Escherichia coli*, and *Clostridium perfringens*. J. Appl. Poult. Res. 30:100142.

Naing, N. N. 2003. Determination of sample size. Malays. J. Med. Sci. 10:84–86.

Ngai, D. G., A. K. Nyamache, and O. Ombori. 2021. Prevalence and antimicrobial resistance profiles of *Salmonella* species and *Escherichia coli* isolates from poultry feeds in Ruiru Sub-County, Kenya. BMC Res. Notes 14:1–6.

Ngongolo, K., and A. Chota. 2021. Chicken production, flock size, management systems, and challenges in the Dodoma region in Tanzania. Poult. Sci. 100:101136.

Ngongolo, K., and A. Chota. 2022. Effect of sex, age, diseases, and control intervention on chickens' mortality and its financial implications in Dodoma, Tanzania. Poult. Sci. 101:101785.

Ngongolo, K., K. Omary, and C. Andrew. 2021. Social-economic impact of chicken production on resource-constrained communities in Dodoma, Tanzania. Poult. Sci. 100:100921.

Okoli, C., G. Ndujihe, and I. Ogbuewu. 2006. Frequency of isolation of Salmonella from commercial poultry feeds and their anti-microbial resistance profiles, Imo State, Nigeria. Online J. Health Allied Sci. 5:2–3.

Omololu, J., and K. F. Bamidele. 2017. Antimicrobial susceptibility pattern of S. aureus and Salmonella sp isolated from poultry feed sold in Ile Ife, Nigeria. Arch. Clin. Microbiol. 8:3.

Padhi, M. K. 2016. Importance of indigenous breeds of chicken for rural economy and their improvements for higher production performance. Scientifica 2016:2604685.

Pius, L. O., P. Strausz, and S. Kusza. 2021. Overview of poultry management as a key factor for solving food and nutritional security with a special focus on chicken breeding in East African countries. Biology 10:810.

Rukia, S., S. Gabriel, B. Joram, and K. Christopher. 2020. Factors associated with infectious bursal disease vaccination failure in Dar es salaam, Tanzania. J. Vet. Med. Anim. Health 12:99–109.

Saidi, R., G. Shirima, J. Buza, and C. Kasanga. 2020. Factors associated with infectious bursal disease vaccination failure in Dar es salaam, Tanzania. J. Vet. Med. Anim. Health 12:99–109.

Saleque, A., A. Jabeen, S. M. Real, and D. B. Mohakhali. 2016. Small scale poultry rearing in Tanzania—subsistence to surplus production for increase income and improve food and nutrition security. Proceedings of XXV World's Poultry Congress. Beijing, China.

Sambo, E., J. Bettridge, T. Dessie, A. Amare, T. Habte, P. Wigley, and R. M. Christley. 2015. Participatory evaluation of chicken health and production constraints in Ethiopia. Prev. Vet. Med. 118:117–127.

Shemsanga, C., A. N. N. Muzuka, L. Martz, H. C. Komakech, E. Elisante, M. Kisaka, and C. Ntuza. 2017. Origin and mechanisms of high salinity in Hombolo Dam and groundwater in Dodoma municipality Tanzania, revealed. Appl. Water Sci. 7:2883–2905.

Shepelo, G., and N. Maingi. 2014. Major causes of poultry mortality in Nairobi and its environs established from autopsies. Kenya Vet. 38:32–42.

Simbizi, V., R. Moerane, G. Ramsay, C. Mubamba, C. Abolnik, and B. Gummow. 2021. A study of rural chicken farmers, diseases and remedies in the Eastern Cape Province of South Africa. Prev. Vet. Med. 194:105430.

Sindiyo, E., and J. Missanga. 2017. Common diseases affecting poultry production in Arusha Peri-urban, Northern Tanzania. J. Appl. Life Sci. Int. 15:1–6.

Skowron, K., J. Bauza-Kaszewska, Z. Dobrzański, Z. Paluszak, and K. J. Skowron. 2014. UV-C radiation as a factor reducing microbiological contamination of fish meal. Sci. World J. 2014:928094.

Swai, E. S., P. N. Sanka, and J. E. Kaaya. 2013. An investigation of the common causes of death in chicken around Arusha Municipality area, Tanzania. Livest. Res. Rural. Dev. 25:204.

Tanzania URT. 2013. The 2012 Population and Housing Census. Population Distribution by Administrative Areas. Tanzania National Bureau of Statistics, Dar es Salaam, Tanzania.

Udhayavel, S., G. T. Ramasamy, V. Gowthaman, S. Malmarugan, and K. Senthilvel. 2017. Occurrence of Clostridium perfringens

contamination in poultry feed ingredients: isolation, identification and its antibiotic sensitivity pattern. Anim. Nutr. 3:309–312.
Ulomi, W. J., F. X. Mgaya, Z. Kimera, and M. I. Matee. 2022. Determination of sulphonamides and tetracycline residues in liver tissues of broiler chicken sold in Kinondoni and Ilala municipalities, Dar es Salaam, Tanzania. Antibiotics 11:1222.
Van Immerseel, F., K. Cauwerts, L. Devriese, F. Haesebrouck, and R. Ducatelle. 2002. Feed additives to control Salmonella in poultry. World's Poult. Sci. J. 58:501–513.
Visvesvara, G. S., and L. S. Garcia. 2002. Culture of protozoan parasites. Clin. Microbiol. Rev. 15:327–328.
Wilson, W. C., M. Slingerland, F. P. Baijukya, H. van Zanten, S. Oosting, and K. E. Giller. 2021. Integrating the soybean-maize-chicken value chains to attain nutritious diets in Tanzania. Food Secur. 13:1595–1612.
Wilson, W. C., M. Slingerland, S. Oosting, F. P. Baijukya, A.-J. Smits, and K. E. Giller. 2022. The diversity of smallholder chicken farming in the Southern Highlands of Tanzania reveals a range of underlying production constraints. Poult. Sci. 101: 102062.
Wojdat, E., K. Kwiatek, and M. Kozak. 2006. Occurrence and characterization of some Clostridium species isolated from animal feeding stuffs. Bull. Vet. Inst. Pulawy 50:63–67.
Yongolo, M. G., H. Christensen, J. E. Olsen, K. Handberg, and U. Minga. 2011. On the origin and diversity of Newcastle disease virus in Tanzania. Onderstepoort J. Vet. Res. 78:1–8.