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Research Article

The Free-Range Production System Decreases Foot Pad Lesions and the Risk of Bacterial Infection in Broilers

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Abstract | Commercial broilers have high growth rates and are raised in total confinement systems. Birds spend more time lying down predisposing them to skin lesions from moist litter. This study aimed to determine whether the free-range production system (FRPS) for broiler birds would reduce foot pad lesions and the risk of bacterial infection. The study followed a completely randomized design, comprising of four treatments and three replications, with each replication consisting of 20 birds. Treatments A, B and C, where the birds were under FRPS at 2, 3 and 4 weeks of age, respectively, and the conventional complete confinement, treatment D (control). The birds were weighed and their foot pad lesions evaluated at 2, 4, 6 and 8 weeks of age. Liver samples were collected at 8 weeks of age and processed for culture and sensitivity. Relative risk analysis (RR) was used to determine the association between confinement as a risk factor and bacterial infection. Birds in the FRPS had lower body weights that probably results less pressure on their skeleton. Treatment D birds had severe foot pad lesions ($P < 0.05$) compared to the other treatments at weeks 6, 7 and 8 and the severity decreased with increasing duration of FRPS. Complete confinement treatment was significantly associated with bacterial infection (RR = 3) at week 8. These results show that broilers in FRPS had significantly lower body weight and fewer foot pad lesions, reducing bacterial infection and antibiotic use. Reduced antibiotic residues and pathogens in meat suggest improved meat quality. The free-range broiler production system would be a better production system to improve the welfare and quality of the meat produced.

Keywords | Antibiotic resistance, Broiler welfare, Conventional broiler, Pad dermatitis, Pathogen portal of entry

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INTRODUCTION

Over the past 60 years, genetic selection has improved conventional broiler growth rates and meat yield. Between 1957 and 2005, broiler growth rates increased by more than 400% (Zuidhof et al., 2014), with more than 80% of this increase being directly attributed to genetic selection and the remaining 20% being attributed to dietary improvements (Havenstein et al., 2003). The rapid growth has also resulted in musculo-skeletal diseases, such as leg problems and bone abnormalities (Knowles et al., 2008). These disorders result in weak legs, lameness, reduced locomotion, and birds spending a lot of time lying down, increasing their risk of developing skin lesions from contact with moist litter (Knowles et al., 2008).

The free-range production system (FRPS) promotes exercise and movement in birds, which can enhance their locomotory and scavenging behaviour, as compared to other production systems (Castellini et al., 2017). Studies indi-

cate that physical activity has a positive effect on bone quality, as it encourages bone formation in chickens (Aguado et al., 2017). Beatie et al. (1995) found that chickens and pigs raised in FRPS exhibited better locomotory behaviour such as preening, dust bathing, walking, and exploring, compared to those in other production systems. Poor quality litter has been linked to a higher incidence of foot pad dermatitis (de Jong et al., 2014). Therefore, implementing a FRPS may help reduce the occurrence of foot pad dermatitis in birds, as it reduces their contact with litter.

Foot pad dermatitis is known as foot pad contact dermatitis in chickens because it develops at points of contact with the ground (Hashimoto et al., 2011). Lesions typically start with skin discolouration and progress to inflammation, erosion, and hyperkeratosis, which can lead to ulceration and necrosis of the epidermis (Wyneken et al., 2015) and lameness.

Lameness has been associated with high growth rates in broiler production systems and is a major concern for chicken welfare (Kapell et al., 2012). A gait scoring system for individual birds, such as the Bristol gait scoring system, with scores ranging from 0 (normal) to 5 (unable to walk), can be used to assess the level of lameness in broiler production systems (Kestin et al., 1992). According to established scoring systems, 14 to 50% of broilers have lameness, as indicated by gait scores greater than 3 on a scale of 0-5 (de Jong et al., 2011; Bassler et al., 2013). Lameness is a critical welfare issue linked to pain (McGeown et al., 1999). In studies, lame broilers preferred foods containing analgesics and increased activity when given analgesics (Caplen et al., 2013). Lame birds may also have difficulty getting food and water (Butterworth and Bras, 2013). Lameness also makes it difficult for birds to avoid unfriendly encounters and engage in normal behaviour such as dust bathing (Vestergaard and Sanotra, 1999), foraging, walking, and preening (Weeks et al., 2000), putting their welfare at risk. Studies have also linked lameness in broiler production systems to low final slaughter weight (Gocsik et al., 2014) and high mortality (Wideman et al., 2012).

Pathogens enter skin lesions, including foot pad lesions, causing complications and developing other lesions such as cellulitis, gangrenous dermatitis, and osteomyelitis (Gornatti-Churria et al., 2017). Due to the broken epithelial lining of the foot pad, pathogens can enter vital organs and predispose broilers to fatal infection. Furthermore, the prevalence of infections caused by gram-positive organisms increases during the production cycle (Thøfner et al., 2019) which directly affects meat quality. Antibiotic resistance caused by antibiotic use in broiler production systems is a worldwide concern (Garcia-Migura et al., 2014). Antibiotics are widely used in food animals, serving as a reservoir of antibiotic-resistant bacteria that can be transferred to humans (Marshall and Levy, 2011). This means that the effectiveness of these antibiotics in humans is declining, resulting in treatment failures (Mellata, 2013). The objective of this study was to determine the effects of FRPS on foot pad lesions and the risk of bacterial infections in broiler.

MATERIALS AND METHODS

Statement of Animal Rights

The study was approved by the Pwani University Ethics and Review Committee. It was carried out according to the ethical standards of the Declaration of Helsinki of 1964 and its subsequent amendments (World Medical Association, 2001).

Study area

This study was conducted on a poultry farm at Pwani University at latitude 2° south, longitude 40° east and altitude 16 m above sea level. The annual rainfall at the study site ranges from 900 to 1100 mm and the mean annual temperature ranges from 25 to 30 ° C (Climate Data, 2017). It has a marked dry season from January to March and a wet season from April to June. The amount and distribution of rain varies throughout the rest of the year.

Experimental Design

The study followed a completely randomized design, comprising of four treatments and three replications, with each replication consisting of 20 birds. The stocking density was 20 square feet per bird in the FRPS area. Two hundred and forty Cobb 500-day-old broiler chicks were purchased from a local hatchery (Kenchic Ltd). On arrival, the chicks were brooded in complete confinement in an intensive deep litter floor system and fed a conventional broiler diet for 2 weeks. At 2 weeks of age, broiler chicks were randomly assigned to four treatments designated A, B, C, and D, that is, (i) treatment A: Complete confinement broiler production system on a conventional broiler diet for 2 weeks, followed by a free-range production system for 6 weeks without commercial feed supplementation; (ii) treatment B: Complete confinement broiler production system on a conventional broiler diet for 3 weeks, followed by a free-range production system for 5 weeks without commercial feed supplementation; (iii) treatment C: Complete confinement broiler production system on a conventional broiler diet for 4 weeks, followed by a free-range production system for 4 weeks without commercial feed supplementation, and (iv) treatment D (control): Complete confinement broiler production system on a conventional broiler diet for the entire experimental period of 8 weeks. All birds were vaccinated against New Castle disease at day14 and received a booster dose at day 28. The birds in FRPS were allowed to roam freely with access to grass

from 7:00 am to 6:30 pm and spent the night in the pens. All birds in all treatments had free access to clean drinking water *ad libitum*.

Weight of the birds

At the age of 2, 4, 6 and 8 weeks, three birds were randomly selected from each replication of all the treatments and weighed for growth performance measurement and later euthanized by cervical dislocation for collection of liver samples.

Scoring of foot pad lesions

Three birds were randomly selected from each treatment at 2, 4, 6 and 8 weeks of age and scored for foot pad lesions. The scoring was done on a scale of 1-5 as described by (Eichner et al., 2007), with minor modifications as described in (Table 1).

Table 1: The score and the description of corresponding lesions.

Score	Description of the injury
1	Footpad without lesion and without pain under mild pressure
2	Footpad with lesions covering less than 50 % of the pad and pain when applying mild pressure
3	The lesion covers 50-75% of the footpad, with pain when applying mild pressure.
4	Lesion covering more than 75% but less than 100% of the pad with pain evidenced by limping
5	Lesion that covers 100% of the footpad extending to the toes, including those unable to walk. The few that walk favour one limb.

Bacteriological tests

Liver samples were collected aseptically at the slaughter of three randomly selected birds from each pen at week 8. The samples were placed in a transport medium, labelled, and immediately transported under a cold chain to the bacteriology laboratory at The Veterinary Investigation Laboratory, Mariakani, Kenya. The culture and identification of bacteria was performed using standard microbiological and biochemical tests (Carter et al., 1990). The samples were streaked on blood agar and MacConkey agar medium and colony morphology was observed after incubation at 37 ° C for 24 h. The Gram stain and cellular characteristics of pure isolated colonies were then determined. Antibiotic sensitivity discs were used to test the sensitivity of isolates to commonly used antibiotics.

Statistical analysis

The study was a completely randomized design with one factor (FRPS) and two response variables (body weight and foot pad scores). The animal body weight data was subjected to one way analysis of variance (ANOVA) using R data management statistical analysis (RStudio, 2020) because it was parametric. Differences among treatment means were separated using the Tukey method ($P < 0.05$). Foot scoring data are ordinal; therefore, the non-parametric Kruskal Wallis test was used ($P < 0.05$), and the means were separated using Dunn's multiple range test.

Relative risk

The risk was exposure of broilers to confinement that resulted in foot pad lesions leading to infection. The relative risk (RR) was, therefore, calculated as the ratio or probability of obtaining pathogenic bacteria isolates from broilers exposed to confinement to the probability of obtaining pathogenic bacteria isolates where broiler birds had exposure to free-range production system.

The formula used in the calculation of RR is given below.
RR = (PE) / (PU)

Where RR = relative risk, PE = probability of the event in the exposed treatment, and PU = probability of the event in the non-exposed treatment.

RR less than 1 indicated less risk of infection, while RR greater than 1 indicated a higher risk of infection. The confidence interval of the RR was calculated using the statistical software MedCalc (Version 20.305). The relative risk was interpreted as different ($P < 0.05$) if the interval did not include unity.

RESULT

Broiler body weights

The FRPS had significant effect ($P < 0.05$) on the body weight (Table 2). There were no treatment differences ($P > 0.05$) in body weight at week 2. At week 4, there were differences ($P < 0.05$) in body weight between treatments B and A, C and A, and D and A, and there were no differences ($P > 0.05$) between treatment D and C. At week 6, there were differences ($P < 0.05$) in body weight between treatments B and A, C and A, D and A and D and B but no difference ($P > 0.05$) in body weight between treatments C and B. At week 8, there were differences ($P < 0.05$) in body weight in treatments C and A, D and A, C and B, and D and C, but no difference ($P > 0.05$) in body weight between treatment B and A (Table 3).

Foot pad lesions

At two weeks of age, there were no lesions and the foot pad score was the same (score 1) for all treatments (Figure 1). At week 4, lesions were observed in birds under treatments B, C, and D. There were no lesions in the birds under treatment A. At week 4, there was a general increase

Table 2: Main effects of treatment (free-range production system, FRPS) on the body weight of broilers.

Weight	Treatment			
	A	B	C	D
Mean weight at 8 weeks of age (grams)	1368±51	1781±107.5	2504±241	3601±202.3
Mean weight at 2 weeks of age (grams)	550.7±46.5	550.1±15.0	552.7±31	551.3±10.5
Mean increase in weight (grams)	817.2[a]	1231[b]	1952[c]	3049[c]

Where p-value = 6.733e-14, F = 67.122 and df = 3

[abc] means in the same row with different superscripts are significantly different at P (<0.05).

The exposure to the treatment (FRPS) was for a period of 6, 5, 4 and 0 weeks for treatments A, B, C, and D respectively.

Table 3: The effects of free-range production system on mean body weight of broilers at 2, 4, 6 and 8 weeks of age.

Week	Comparison of mean body weight	Mean rank difference	P-value
2	B-A	0.556	1.00
	C-A	2.000	1.00
	D-A	0.667	1.00
	C-B	2.556	1.00
	D-B	1.222	1.00
	D-C	-1.333	1.00
4	B-A	315.889	0.00*
	C-A	700.667	0.00*
	D-A	695.556	0.00*
	C-B	384.778	0.00*
	D-B	379.667	0.00*
	D-C	-5.111	1.00
6	B-A	464.333	0.00*
	C-A	774.333	0.00*
	D-A	1939.333	0.00*
	C-B	310.000	0.07
	D-B	1475.000	0.00*
	D-C	1165.000	0.00*
8	B-A	413.556	0.06
	C-A	1136.333	0.00*
	D-A	2232.667	0.00*
	C-B	722.778	0.00*
	D-B	1819.111	0.00*
	D-C	1096.333	0.00*

Note: B-A implies the comparison of the mean body weight of the broilers in treatment A with those in treatment B. The same applies to all rows per week; Comparisons with statistical difference (P < 0.05) are indicated by *.

in the average scores for all treatments except treatment A, which remained at a score of 1. Treatment C and D recorded a high score of 1.8, while treatment B recorded a lower score of 1.2.

However, there was no difference between the scores (P > 0.05) at week 4 (Table 4). By week 6, the average score for treatment D had increased to 2, while that for treatment C decreased to 1.3 (Figure 1). Treatment B also reduced its average score to the same level as treatment A (score of 1). The difference (P < 0.05) between the scores of control D and the other treatments (A, B, and C) was observed at weeks 6 (Table 4). At week 8, the control (D) average score continued to increase to 3.3 while treatment C decreased further to 1.2. Treatments A and B remained constant with a previous score of 1. The difference (P < 0.05) between the scores of control D and the other treatments (A, B, and C) was observed at week 8 (Table 4). Some treatments recorded severe foot pad lesions extending to the digits registering a score of 5 (Figure 2)

Table 4: Effect of the free-range production system on foot pad lesion scores at weeks 2, 4, 6 and 8 of age.

Week	Treatment comparison		Estimate	Confidence interval	P-Value
2	A	B	-0.222	-0.504-0.060	0.16
	A	C	-0.222	-0.504-0.059	0.16
	A	D	-0.222	-0.504-0.059	0.16
	B	C	0.000	-0.282-0.282	1.00
	B	D	0.000	-0.282-0.282	1.00
	C	D	0.000	-0.282-0.282	1.00
4	A	B	0.111	-0.491-0.713	0.96
	A	C	0.333	-0.269-0.935	0.45
	A	D	0.556	-0.047-1.158	0.08
	B	C	0.222	-0.380-0.824	0.75
	B	D	0.444	-0.158-1.047	0.21
	C	D	0.222	-0.380-0.824	0.75
6	A	B	0.000	-0.563-0.563	1.00e+00
	A	C	0.667	0.103-1.230	1.53e-02*
	A	D	1.444	0.881-2.008	4.00e-07*
	B	C	0.667	0.103-1.230	1.53e-02*
	B	D	1.444	0.881-2.008	4.00e-07*
	C	D	0.778	0.215-1.341	3.82e-03*
8	A	B	0.000	-0.439-0.439	1.00
	A	C	0.444	0.006-0.883	0.04*
	A	D	3.778	3.339-4.217	0.00*
	B	C	0.444	0.006-0.883	0.04*
	B	D	3.778	3.339-4.217	0.00*
	C	D	3.333	2.894-3.772	0.00*

Note: Comparisons with statistical difference ($P < 0.05$) are indicated by *.

Table 5: Relative risk analysis for bacterial infections.

Treatment	% with bacterial isolate	% without bacterial isolate	Total	Relative risk	Confidential interval	P-value
A	22	78	100	1.0	0.59-1.69	1.000
B	33	67	100	1.5	0.94-2.38	0.09
C	55	45	100	2.5	1.66-3.76	< 0.0001
D	66	34	100	3.0	2.02-4.45	< 0.0001

Table 6: Antibiotic susceptibility patterns of broiler liver isolates.

Antibiotic	*Staphylococcus aureus*			*Escherichia coli*			*Citrobacter freundii*		
	Susceptible (%)	Intermediate (%)	Resistant (%)	Susceptible (%)	Intermediate (%)	Resistant (%)	Susceptible (%)	Intermediate (%)	Resistant (%)
Ampicillin	84	-	16	100	-		100	-	
Tetracycline	26	21	53	-	-	100	-	100	-
Chloramphenicol	84	11	5	100	-	-	100	-	-
Kanamycin	26	6	68	100	-	-	100	-	-
Streptomycin	68	16	16	-	-	100	-	-	100
Sulfamethoxazole	52	16	32	-	-	100	-	-	100

Cotrimoxazole	21	5	74	-	-	100	-	-	100
Gentamycin	100	-	-	100	-	-	100	-	-

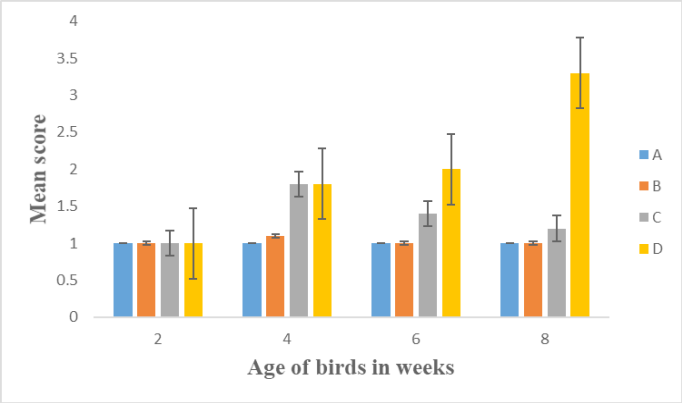

Figure 1: The effects of free-range production system on footpad lesion scores at 2, 4, 6 and 8 weeks of age.

Figure 2: Foot pad lesions in a 6-week-old broiler (A-Pad lesions; B-Lesions extending to the digits) representing a score of 5.

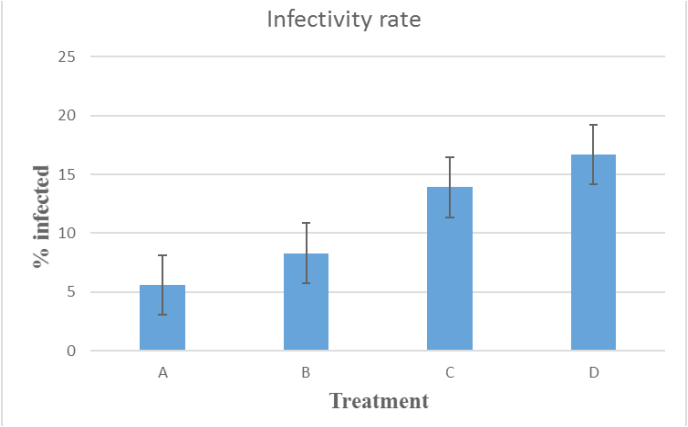

Figure 3: The effects of the free-range production system on the mean percentage of infected liver by *Staphylococcus aureus*, *Escherichia* and *Citrobacter freundii* species at 8 weeks of age.
Most of the livers sampled in treatment D were enlarged and friable.

Relative risk

The birds in confinement (treatment D) had a relatively higher risk of being infected with bacteria than the birds in FRPS (treatments A, B and C). The risk decreased with increasing exposure to FRPS. Birds in treatments B, C and D had RR of 1.5, 2.5 and 3, respectively, compared to birds in treatment A which had an RR of 1 (Table 5). Broiler birds were three times more likely to be infected with pathogenic bacteria in complete confinement than when allowed six weeks of FRPS. Birds were 2.5 times more likely to be infected with bacteria at four weeks of FRPS than at six weeks. The association between the duration of confinement and the isolation of bacteria was different ($P < 0.05$) for birds in treatments D (complete confinement) and C (4 weeks of confinement) (Table 5).

Bacterial isolation and resistance to microbes

Bacteria were isolated from 5.6%, 8.3%, 13.9% and 16.7% of birds sampled from treatments A, B, C and D, respectively (Figure 3). *Staphylococcus aureus* isolates were found in 19 of the 36 liver samples, while *Escherichia coli* and *Citrobacter freundii* isolates were found in only one sample each.

Antibiotics commonly used in poultry production recorded the highest percentage of resistance to *Staphylococcus aureus*. And this includes tetracyclines (53%), cotrimoxazole (74%) and sulfamethoxazole (32%). The antibiotics less commonly used in poultry production recorded the least resistance to *Staphylococcus aureus*. Ampicillin (16%), chloramphenicol (5%) and gentamycin (0%) followed this trend. The same was observed for *Escherichia coli* and *Citrobacter freundii* isolate resistance for poultry antibiotics commonly used: tetracycline (100%), sulfamethoxazole (100%) and cotrimoxazole (100 %). For the antibiotic not commonly used in poultry production, resistance was minimal or zero (gentamycin (0%), chloramphenicol (0%) and ampicillin (0%) (Table 6).

DISCUSSION

Free-range production system appears to slow broiler growth. This is consistent with previous research, which discovered a similar negative relationship between body weight and FRPS use (Campbell et al., 2017). Although some authors have found the opposite relationship (Singh et al.,, 2016). Rapid growth has also caused musculoskeletal disorders such as leg problems and bone deformations (Knowles et al., 2008). These disorders cause leg weakness,

lameness, reduced locomotor activity, and birds spend a lot of time lying down in contact with moist litter, predisposing them to skin lesions (Knowles et al., 2008). As a result, the weight of the broilers is an important factor in their welfare. This can be mitigated by having FRPS, which slows the growth rate and thus reduces stress and other negative effects in these birds.

The lameness of birds in intensive broiler production systems is a vital welfare concern, as it is associated with pain (McGeown et al., 1999). It has been reported that there is usually a high prevalence of foot pad lesions, which develop as early as 1 week of age and increase both in severity and incidence with age in broilers (Hashimoto et al., 2011). This is like the findings of the current study in that the broiler foot pad's lesions progressively deteriorated over time when subjected to confinement. Some lesions were so severe that they covered 100% of the foot pad and extended to the digits. This observation agrees with (Kaukonen et al., 2016), who observed that the integrity of the broiler foot pad was compromised when subjected to continuous confinement. The broiler foot pad lesions improved greatly on exposure to FRPS. This agrees with (Ennis et al., 2013) who found that in non-infected foot pad lesions, the inflammatory response decreased and was replaced by angiogenesis and tissue re-modelling when the confinement pressure was lifted on the birds. The FRPS birds showed fewer foot pad lesions than those without FRPS (Heerkens et al., 2016; Rodriguez-Aurrekoetxea and Estevez 2016).

Furthermore, studies have shown that foot pad lesions are affected by the production system (Cengiz et al., 2013). The effect of the production system was evident in this study because FRPS birds had a lower incidence of the lesions. However, these findings were contrary to those of (Larsen et al 2018), who found no relationship between FRPS and foot pad lesions, plumage, keel bone condition, beak, and comb colour. The current study compared two systems; confinement of broiler birds versus broilers having FRPS. On the other hand, Larsen was studying laying hens in one system (FRPS) and their ability to utilize the available opportunities in the same system. Larsen's research implies that most of the predisposing factors to develop foot pad lesions, such as litter, were not at play in his research. The preceding observation could explain why Larsen's findings differed from the current investigation.

Litter conditions have also been associated with foot pad lesions, especially when lesions occur over a short period (Kaukonen et al., 2017). In this study, all birds had a good quality uniform litter in the conventional broiler production system. It is postulated that those in FRPS had less contact with the litter. From the previous statement, it can be inferred that the effect of litter was minimised on their release from confinement, leading to better foot pad health. (Kyvsgaard et al., 2013) found that foot pad lesions can serve as a portal for the entry of pathogenic bacteria into the body of birds, causing economic losses in an enterprise. Most of the livers sampled, particularly from the treatment in total confinement, were enlarged and friable, possibly due to a higher level of infection with Staphylococcus species. It is hypothesized that the bacteria in the liver entered through the broiler foot pad lesions because these bacteria are common residents (70% of the bacteria) on the skin of vertebrates, including chickens (Nagase et al., 2002). Furthermore, *Staphylococcus aureus* is associated with abscesses in the central foot pads due to damaged epithelium (Heidemann et al., 2018), raising the possibility that other routes of entry, such as oral and respiratory routes, were unlikely routes of pathogen entry into the broiler liver.

The percentage of infection was found to have a relationship with foot pad lesions; the greater the severity of foot pad lesions, the higher the relative risk of the percentage of infection. Therefore, in general, continued confinement of birds was significantly associated with a bacterial infection. Infected foot pad lesions can become more severe with ulceration and inflammation of surrounding tissues, resulting in pain and compromised bird welfare (Bassler et al., 2013).

This study showed that *Staphylococcus aureus* had higher antibiotic resistance to the most used antibiotics in broilers, such as tetracycline (53%) and sulfamethoxazole (32%). This higher resistance to commonly used antibiotics (tetracycline and sulfamethoxazole) contrasts with resistance to less commonly used antibiotics such as gentamycin (0%) and Chloramphenicol (5%). This is consistent with the findings of (Diarra et al., 2014), who discovered that many poultry production systems use antibiotics, putting pressure on the selection of antibiotic resistant bacteria. Similarly, in Africa (Ghana and Nigeria), cattle-associated *Staphylococci* are susceptible to amoxicillin/clavulanic acid, amikacin, ciprofloxacin, gentamycin, and cephalexin (Boamah et al., 2017). In contrast, in the United States, most staphylococcal isolates were susceptible to rifampin, cotrimoxazole, gentamycin, vancomycin, and chloramphenicol (Abdalrahma et al., 2015), which are not commonly used in poultry production systems. However, most of these organisms exhibited high levels of resistance to oxacillin and tetracycline, which would be disastrous if these strains resistant to oxacillin were transferred to humans (Boamah et al., 2017). Antibiotic resistance is a major threat to human and animal health (Harbarth et al., 2015).

CONCLUSIONS

The study found that using FRPS enhances the condition of the foot pads, which in turn decreases discomfort and improves the well-being of birds. Furthermore, this improvement in foot pad health reduces the possibility of infections, leading to a decrease in antibiotic use during production. This results in better quality meat without antibiotic residues and harmful pathogens, and consequently, it is anticipated that an FRPS could help to reduce antibiotic resistance. It is necessary to carry out comparable research with indigenous breeds and other fast-growing breeds like Cornish Rock and Rosambro to further enhance the welfare of chickens and the wholesomeness of meat.

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CONFLICT OF INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

NOVELTY STATEMENT

Consumer awareness and demand for ethically produced and healthier animal products in broiler production systems is growing. This study fills the gap in scientific evidence supporting claims of increased broiler welfare in free-range settings, thereby impacting consumer choices and industry behavior. Overall, it aimed to give an understanding of the benefits of the FRPS in decreasing foot pad lesions and bacterial infection risks in broilers, resolving information gaps, and contributing to more sustainable and welfare-conscious chicken farming practices.

AUTHORS' CONTRIBUTION

All authors contributed equally to the development of the manuscript.

DATA AVAILABILITY

The data sets generated during and/or analysed during the current study are not publicly available due to the fact that they are at Pwani University Library undergoing the process of availing them online but are available from the corresponding author on reasonable request.

CONSENT TO PARTICIPATE

The manuscript does not contain clinical studies or patient data.

CONSENT TO PUBLISH

All authors have read and agreed publication of the manuscript and that the manuscript has not been published or submitted to other journals. They also agree to the conditions outlined in the copyright assignment form.

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