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Risk of Acquiring Staphylococcal Food Poisoning Zoonosis from the Co-Habitation of Companion Dogs and Humans in Edo and Delta States, Nigeria

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ABSTRACT

In Nigeria, the number of households that keep companion animals has been steadily increasing. This study was designed to perform a cross-sectional analysis of the risk of zoonotic staphylococcal food poisoning transmitted through the cohabitation of dogs and humans in Edo and Delta States of Nigeria. A structured questionnaire was employed for data collection, and both phenotypic and 16S rRNA gene sequencing were used to identify the presence of *Staphylococcus aureus*. Enterotoxin production in the *S. aureus* was assessed with the Staphylococcal Enterotoxin Reversed Passive Latex Agglutination (SET-RPLA) assay. Risk assessments were conducted using the U.S. FDA-iRisk stochastic software to evaluate potential health impacts. Results showed that, a significant proportion of dog owners reported sharing their kitchens (55%), bedrooms (46%), and household furniture (66%) with their pet dogs. The chi-square test of independence indicated a statistically significant association ($p < 0.05$) between living with dogs and the likelihood of contracting zoonotic infections. Staphylococcal risk of staphylococcal food poisoning was higher in Edo State compared to Delta State, particularly during the rainy season, with estimates of 831 cases per 10,000 servings of contaminated yam in Edo State versus 702 cases per 10,000 servings in Delta State. The findings suggest a considerable potential for the transmission of staphylococcal bacteria and enterotoxins between dogs and humans within household settings.

Keywords: Zoonosis, Companion Dogs, Kitchens, Yams, Bedrooms, Furniture, *Staphylococcus aureus*; Enterotoxins; Risk.

Introduction

Recent studies and observations emphasize a growing trend of companion animals kept within households (Meseko, 2010; FEDIAF, 2012; Raheem, 2017; Adeola *et al.,* 2022; Adeola *et al*., 2024). These animals, commonly referred to as companion animals, are those animals kept by humans primarily for company and emotional sustenance (Damborg *et al*., 2016). The coat of dense hair covering the skin of companion dogs, known as fur, serves multiple functional roles, including protection against microbial, chemical, and physical harm (Miller *et al*., 2013; Cusco *et al*., 2017).

It has been frequently documented that the fur on companion dogs can act as a reservoir harboring many pathogenic bacteria (Wang *et al*., 2019; Suepaul *et al*., 2021). Consequently, zoonotic diseases may be transmitted through direct contact with these animals or indirectly via cross-contamination of foodstuffs.

Numerous reports have identified coagulase-positive *Staphylococcus aureus* colonizing the fur and skin of companion dogs (Wang *et al*., 2019; Suepaul *et al*., 2021). *Staphylococcus aureus* is well known for producing potent toxins in food, which can lead to various foodborne illnesses, including staphylococcal food poisoning, sepsis-related infections, and toxic shock syndrome in humans (Chiang et al., 2008; Ostyn et al., 2010; Thomas et al., 2013; Kadariya et al., 2014; Kirk et al., 2014; Lee et al., 2015; Park et al., 2015; Van Cauteren et al., 2017; Fisher et al., 2018; Adeola et al., 2022; Adeola et al., 2024). The classical set of staphylococcal gastrointestinal toxins includes enterotoxins A through E (SEA, SEB, SEC, SED, SEE), which are commonly associated with inducing vomiting. Besides, newer enterotoxins such as SEM, SEN, SEO, SEP, SEQ, SEG, SEH, SEI, SEJ, SEK, SET, SEU, SEL, SER, SES, SEW, SEV, SEY, and SEX whose emetic activities are still under investigation have also been identified (Asao et al., 2003; Le Loir et al., 2003; Fisher et al., 2014; Regenthal et al., 2017; Toubar et al., 2018).

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Remarkably, as little as 0.1 µg of staphylococcal enterotoxins present in food (Le Loir et al., 2003; Larkin et al., 2009), or the detection of enterotoxin-producing *S. aureus* at a concentration of at least 10^5 CFU/g of food (Hennekinne et al., 2012; Kadariya et al., 2014; Fetsch and Johler, 2018), has been linked to outbreaks of staphylococcal food poisoning. This condition is characterized by symptoms such as vomiting, nausea, and abdominal cramps, with or without diarrhea, typically manifesting within three to nine hours post-consumption (Le Loir et al., 2003; Murray, 2005; Argudin et al., 2010; Kadariya et al., 2014; Fisher et al., 2018).

Companion dogs are reservoirs for a diverse range of *Staphylococcus* species (Simoons-Smit et al., 2000; Boost et al., 2008; Filippitzi et al., 2017; Haag et al., 2019; EFSA, 2020; Bertelloni et al., 2021). Studies have shown that certain species produce enterotoxins capable of causing staphylococcal food poisoning outbreaks in humans (Abdel-moein and Samir, 2011; Gonzalez-Martín et al., 2020; Bertelloni et al., 2021). From both medical and veterinary perspectives, it is essential to understand the potential risk of humans being exposed to enterotoxin-producing *S. aureus* carried by pet dogs. Risk assessment generally involves predicting the likelihood of staphylococcal food poisoning cases through established procedures such as hazard identification, exposure assessment, hazard characterization, and overall risk characterization (Codex Alimentarius Commission, 1999; Palisade Corporation, 2010; FDA/CFSAN/JIFSAN/RSI, 2021).

The current study aimed to conduct a cross-sectional investigation into the potential for zoonotic staphylococcal food poisoning resulting from the cohabitation of companion dogs and humans in Edo and Delta States of Nigeria. The study was intentionally carried out during two distinct periods of the dry season and the rainy season to assess the risk of staphylococcal food poisoning zoonosis across different environmental conditions.

Materials and Methods

Study sites

The study sites comprised residential homes housing companion dogs, selected from two locations: Benin City and Sapele, situated respectively in Edo (latitude: 6.5438°N, longitude: 5.8987°E) and Delta (latitude: 5.7040°N, longitude: 5.9339°E) States located in the South-South geopolitical zone of Nigeria. A total of fifty households were included in the study, with twenty-three (23) homes from Delta State and twenty-seven (27) from Edo State.

Enrolled companion dogs for the study

For this study, only healthy companion dogs without any clinical signs of illness were included, whereas dogs exhibiting signs of disease were excluded. The breeds of the enrolled companion dogs encompassed American Eskimo, Alsatian, Caucasian Shepherd, German Shepherd, Lhasa Apso, and Doberman Pinscher. The study used records from twelve (12) veterinary clinics within the designated localities to identify the homes of dog owners. Prior to sampling, informed consent was obtained from the owners of the companion dogs. A total of 70 dogs participated in the study, with thirty-five (35) dogs recruited from Edo State and an additional thirty-five (35) from Delta State.

Study design

This descriptive study employed a cross-sectional design, using a structured questionnaire (Figure 1).

QUESTIONNAIRE USED TO OBTAIN DATA ON THE BEHAVIOURAL ASPECTS OF THE CO-HABITATION OF HUMANS AND COMPANION DOGS

PART A: SOCIO-DEMOGRAPHIC SURVEY OF DOG OWNERS

Q1. **Gender**: Male [ ] Female [ ]
Q2. **Age group**: Less than 20 years [ ] 21-30 years [ ] 31-40 years [ ] 41-50 years [ ] Greater than 50 years [ ]
Q3. **Marital status**: Married [ ] Single [ ]
Q4. **Educational status**: No formal education [ ] Primary [ ] Secondary [ ] Tertiary [ ]
Q5. **Occupation**: Healthcare [ ] Others [ ]
Q6. **Religion**: Christianity [ ] Islam [ ] Traditional [ ] Others [ ]

PART B: SURVEY OF THE SOCIAL INTERACTIONS BETWEEN THE COMPANION DOGS AND THEIR OWNERS

Q1. **How many persons are in your home?** 1 – 4 [ ] 5 or more [ ]
Q2. **How many dog(s) do you keep at home?** 1 dog [ ] 2 dogs [ ] 3 or more dogs [ ]
Q3. **What other companion animals do you keep at home?** Cat [ ] Bird [ ] None [ ]
Q4. **Do you regularly rub the fur on the skin of your dog with your hands?** Yes [ ] No [ ]
Q5 **Do you regularly wash your hands after rubbing the skin of your dog?** Yes [ ] No [ ]
Q6 **Do you regularly carry your dog in your arms?** Yes [ ] No [ ]
Q7. **Do you kiss your dog?** Yes [ ] No [ ]
Q8. **Do you allow your dog to lick your hands?** Yes [ ] No [ ]
Q9. **Do you allow your dog to lick your face?** Yes [ ] No [ ]
Q10. **Do you allow your dog to have access to your kitchen?** Yes [ ] No [ ]
Q 11. **Do you allow your dog to have access to your bedroom?** Yes [ ] No [ ]
Q12. **Do you allow your dog to sit or lie on your household furniture?** Yes [ ] No [ ]
Q13. **Do you regularly bath your dog?** Yes [ ] No [ ].

Fig. 1: Questionnaire completed by the dog owners

The questionnaire aimed to gather comprehensive socio-demographic information about dog owners, and details regarding the social interactions involved in the coexistence of humans and their companion dogs. Dog owners completed the questionnaires and submitted them immediately prior to the sampling of their dogs. The sampling was carried out during two distinct periods: January to March 2020, representing the dry season, and July to October 2020, corresponding to the rainy season. This timing was intentional to assess the risk of staphylococcal food poisoning zoonosis across different environmental conditions. The sampling of the companion dogs employed methods outlined by Cusco *et al.* (2017), while a risk assessment was performed using FDA-iRisk software, version 4.2 (FDA/CFSAN/JIFSAN/RSI, 2021).

Food contamination modelling mediated by companion dog

The pathway of staphylococcal food poisoning was simulated through a scenario involving pre-sterilized yams, a staple food in Nigeria. Specifically, twenty-five grams (25g) of each raw yam sample, with a surface area of 25 cm^2, were sterilized by autoclaving the yam wrapped in aluminum foil at a temperature of 121°C for 15 minutes. To prepare for handling, the palms of human hands were thoroughly sanitized by first scrubbing with soap, followed by a rinse with sterile water containing 5000 ppm of hypochlorite, and concluding with a final rinse in sterile water before being used to rub the fur of dogs. The model of food contamination was based on a scenario where each pre-sterilized yam was cross contaminated by sanitized human palms previously contaminated through rubbing on the lumbar fur of companion dogs.

Screening of companion dog and yam samples for presence of enterotoxin-producing *S. aureus*

The screening of the companion dogs was conducted by swabbing a 125 cm^2 area of fur located on the lumbar region of each animal. Ten moist swab sticks were used to collect samples from each dog, which were then placed into sterile bottles containing 30 ml of sterile phosphate-buffered saline, as described by Cusco et al. (2017). The samples were subsequently inoculated onto Mannitol Salt Agar (MSA) plates using the spread plate method (Public Health England, 2014). The concentration of *S. aureus* was expressed as colony-forming units per square centimeter (CFU/cm^2) of the dog's fur surface.

The screening of cross-contaminated yam samples was conducted using a spread plating method. In this process, 25 grams of each yam sample were homogenized in 225 milliliters of phosphate-buffered saline, allowing for the preparation of serial dilutions. These dilutions (10^{-1} to 10^{-4}) were then inoculated onto Mannitol Salt Agar (MSA) plates, and presumed staphylococcal colonies were counted and initially identified using phenotypic techniques (Krieg and Holt, 1984; Sneath et al., 1986). The concentration of *S. aureus* was expressed as colony-forming units per gram (CFU/g) of yam based on the results obtained.

The ability of *S. aureus* isolates to produce enterotoxins was assessed through Staphylococcal Enterotoxin Reversed Passive Latex Agglutination (SET-RPLA) assay (Rose et al., 1989).

Molecular identification of enterotoxin-producing *Staphylococcus aureus*

The molecular identification of enterotoxin-producing *S. aureus* was performed through 16S rRNA gene sequencing following protocols outlined by Krieg and Holt (1984), Sneath et al. (1986), Lane (1991), and Schuurman et al. (2004).

Description of the risk assessment model

The risk assessment employed a quantitative approach using numerical equations to analyze the behavior of enterotoxin-producing *S. aureus* on ready-to-eat (RTE) yam. The process modeling of the exposure pathway was grounded in experimental analysis, which provided the initial dataset of exposure parameters including the concentration and prevalence of the pathogen sourced from yam samples contaminated by companion dogs. These variables were subsequently represented as probability distributions and fed into the stochastic FDA-iRisk software, which performed Monte Carlo simulations to explicitly characterize the uncertainty and variability fundamental in these parameters. Besides, Monte Carlo simulations (FDA/CFSAN/JIFSAN/RSI, 2021) were conducted on the body weight data of the general human population (ages 2 to 75) who consume yams. These body weights, combined with standard serving size assumptions, and assisted detailed consumption modeling. During dose-response modeling, the reciprocal of the infectious dose of *S. aureus* (the r-parameter), was also entered into the FDA-iRisk system to generate a dose-response curve.

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The simulation outputs provided estimations of the likelihood of staphylococcal food poisoning cases, comprehensive of associated uncertainties (FDA/CFSAN/JIFSAN/RSI, 2021).

Statistical analysis

Descriptive statistical analyses of *S. aureus* and its relative occurrence datasets were conducted using NCSS version 12 data analysis software. This included the application of descriptive statistics, the Shapiro Wilk test for normality, Levene's test for homogeneity of variances, the Kruskal Wallis nonparametric one-way ANOVA, and the Chi-square test. These tests were conducted to evaluate the association between human-dog cohabitation and the risk or likelihood of zoonotic infection transmission (Number Cruncher Statistical Software, 2025). A significance level of $p < 0.05$ was adopted for hypothesis testing. Also, the FDA-iRisk software version 4.2 was employed to perform Monte Carlo simulations to model the probability of staphylococcal food poisoning cases stemming from colonized companion dogs harboring enterotoxin-producing *S. aureus* (FDA/CFSAN/JIFSAN/RSI, 2021).

Results

Table 1 presents the demographic profile of the dog owners involved in this study from their response to questionnaire. A total of fifty (50) dog owners consented to participate, all of whom permitted their dogs to be sampled and completed the questionnaires.

Table 1: Socio-demographic survey of dog owners

Socio-demographic parameters		Statistical parameters	
		Mean ± SE of mean (N = 50) %	95% CI of mean (N = 50) %
Sex	Male	92.00 ± 3.88	84.40 – 99.60
	Female	8.00 ± 3.88	0.40 – 15.60
Age	< 20 years	0.00 ± 0.00	0.00 – 0.00
	21 – 30 years	8.00 ± 3.88	0.40 – 15.60
	31 – 40 years	34.00 ± 6.77	20.74 – 47.26
	41 – 50 years	44.00 ± 7.09	30.10 – 57.90
	> 50 years	14.00 ± 4.96	4.29 – 23.72
	Respondent did not specify	0.00 ± 0.00	0.00 – 0.00
Marital status	Married	90.00 ± 4.29	81.60 – 98.40
	Single	6.00 ± 3.39	0.00 – 12.63
	Respondent did not specify	4.00 ± 2.80	0.00 – 9.49
Educational status	No formal education	2.00 ± 2.00	0.00 – 5.92
	Primary	4.00 ± 2.80	0.00 – 9.49
	Secondary	20.00 ± 5.71	8.80 – 31.20
	Tertiary	74.00 ± 6.27	61.72 – 86.28
	Respondent did not specify	0.00 ± 0.00	0.00 – 0.00
Occupation	Healthcare	6.00 ± 3.39	0.00 – 12.63
	Others	94.00 ± 3.39	87.35 – 100.00
	Respondent did not specify	0.00 ± 0.00	10.39 – 19.21
Religion	Christianity	78.00 ± 5.92	66.40 – 89.60
	Islam	6.00 ± 3.39	0.00 – 12.63
	Traditional	14.00 ± 4.96	4.29 – 23.72
	Others	0.00 ± 0.00	0.00 – 0.00
	Respondent did not specify	2.00 ± 2.00	0.00 – 5.92

Note: SE = Standard error; CI = Confidence interval; % = percent; N = total number of respondents.

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Table 1 showed that the majority of the participating dog owners were male, accounting for 92% of the sample. Notably, the largest age group among the owners was between 41 and 50 years old, representing 44% of the participants. The majority were married, comprising approximately 90% of the sample, and most held tertiary-level education, with 74% reaching that level. Besides, a significant proportion identified as Christian, making up 78% of the respondents. Only a small fraction, 6%, was employed within healthcare institutions, whereas 94% of the owners were engaged in other occupational roles.

Table 2 provides an overview of some of the social interactions observed between companion dogs and their owners. During the study, it was noted that in 84% of the homes visited, there were between one and four individuals present.

Most dog owners (86%) kept only a single dog at home. None of the households included other companion animals such as cats or birds. Ninety-six per cent (96%) of dog owners reported regularly rubbing their dogs' fur with their hands, although only 14% indicated that they washed their hands with soap and disinfectants afterward. Besides, 76% of owners often carried their dogs in their hands, yet a large majority (94%) stated that they do not kiss or lick their dogs' faces, although 28% admitted to licking their dogs' paws.

About half of the owners (52%) allowed their dogs to have access to the kitchen, and 46% permitted access to their bedrooms. Sixty-six per cent (66%) of owners reported that their dogs sat or lay on household furniture. Finally, just over half (52%) of dog owners reported bathing their dogs regularly.

Table 2: Survey of the social interactions between companion dogs and their owners

Socio-demographic parameters		Statistical parameters	
		Mean ± SE of mean (N = 50) %	95% CI of mean (N = 50) %
Sex	Male	92.00 ± 3.88	84.40 – 99.60
	Female	8.00 ± 3.88	0.40 – 15.60
Age	< 20 years	0.00 ± 0.00	0.00 – 0.00
	21 – 30 years	8.00 ± 3.88	0.40 – 15.60
	31 – 40 years	34.00 ± 6.77	20.74 – 47.26
	41 – 50 years	44.00 ± 7.09	30.10 – 57.90
	> 50 years	14.00 ± 4.96	4.29 – 23.72
	Respondent did not specify	0.00 ± 0.00	0.00 – 0.00
Marital status	Married	90.00 ± 4.29	81.60 – 98.40
	Single	6.00 ± 3.39	0.00 – 12.63
	Respondent did not specify	4.00 ± 2.80	0.00 – 9.49
Educational status	No formal education	2.00 ± 2.00	0.00 – 5.92
	Primary	4.00 ± 2.80	0.00 – 9.49
	Secondary	20.00 ± 5.71	8.80 – 31.20
	Tertiary	74.00 ± 6.27	61.72 – 86.28
	Respondent did not specify	0.00 ± 0.00	0.00 – 0.00
Occupation	Healthcare	6.00 ± 3.39	0.00 – 12.63
	Others	94.00 ± 3.39	87.35– 100.00
	Respondent did not specify	0.00 ± 0.00	10.39 – 19.21
Religion	Christianity	78.00 ± 5.92	66.40 – 89.60
	Islam	6.00 ± 3.39	0.00 – 12.63
	Traditional	14.00 ± 4.96	4.29 – 23.72
	Others	0.00 ± 0.00	0.00 – 0.00
	Respondent did not specify	2.00 ± 2.00	0.00 – 5.92

Note: SE = Standard error; CI = Confidence interval; % = percent; N = total number of respondents.

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Table 3 presents a detailed contingency table used to explore the relationship between human-dog cohabitation within the study population and the potential risk/likelihood of acquiring zoonotic infections. A 2 × 10 contingency table, constructed based on responses from dog owners to questions 3 through 12 shown in Table 2, was used for conducting the Chi-Square test. Owners who did not respond to any of the questions in items 3 to 12 were excluded from the probability calculations relevant to the Chi-Square distribution.

The Chi-Square test of independence revealed a statistically significant relationship ($p < 0.05$; Chi-Square = 146.69) between the presence of human-dog cohabitation and the likelihood of contracting zoonotic infections. This suggests that, especially for dogs carrying infectious agents, there is an enhanced risk of zoonotic transmission, likely due to the close social interactions between these companion dogs and their owners in the studied population.

Table 3: Contingency table for the Chi-square test of independence

Items extracted from Table 2	Human-dog cohabitation Parameters	Probability (risk) of infection				Chi square for presence/absence of risk	
		Presence of risk		Absence of risk			
		K/N	P	K/N	P	X^2	P-value
						3.77	0.93
3.	Regular rubbing of fur on dog's skin with the hands	48/48	1	0/48	0.00		
4.	Regularly wash hands with soap and disinfectants after rubbing dog's skin with the hands	42/49	0.86	7/49	0.14		
5.	Regularly carry the dog in the arms	38/50	0.76	12/50	0.24		
6	Kiss the dog	0/47	0.00	47/47	1.00		
7.	Dog lick the hands	14/36	0.39	22/36	0.61		
8.	Dog lick the face	3/46	0.07	43/46	0.93		
9.	Dog has access to kitchen	26/50	0.52	24/50	0.48		
10.	Dog has access to bedroom	23/45	0.51	22/45	0.49		
11.	Dog sit/lay on household furniture	33/47	0.70	14/47	0.300		
12.	Regularly bath dog	17/43	0.40	26/43	0.60		

Gel electrophoresis of amplified 16S rRNA genes obtained from *S. aureus* and its enterotoxin-producing strains isolated from the companion dogs and RTE yams samples are shown in Figure 1. Representative *S. aureus* strain ADEOLAAKINNIBOSUN 204, *S. aureus* strain ADEOLAAKINNIBOSUN 231, *S. aureus* strain ADEOLAAKINNIBOSUN 232, *S. aureus* strain ADEOLAAKINNIBOSUN 234, *S. aureus* strain ADEOLAAKINNIBOSUN 237, *S. aureus* strain ADEOLAAKINNIBOSUN 239 isolated from the companion dog and RTE yam samples were deposited in the GenBank (NCBI) database under accession numbers MW965613, MZ461457, MZ461460, MZ461462, MZ488454, and MZ488503.

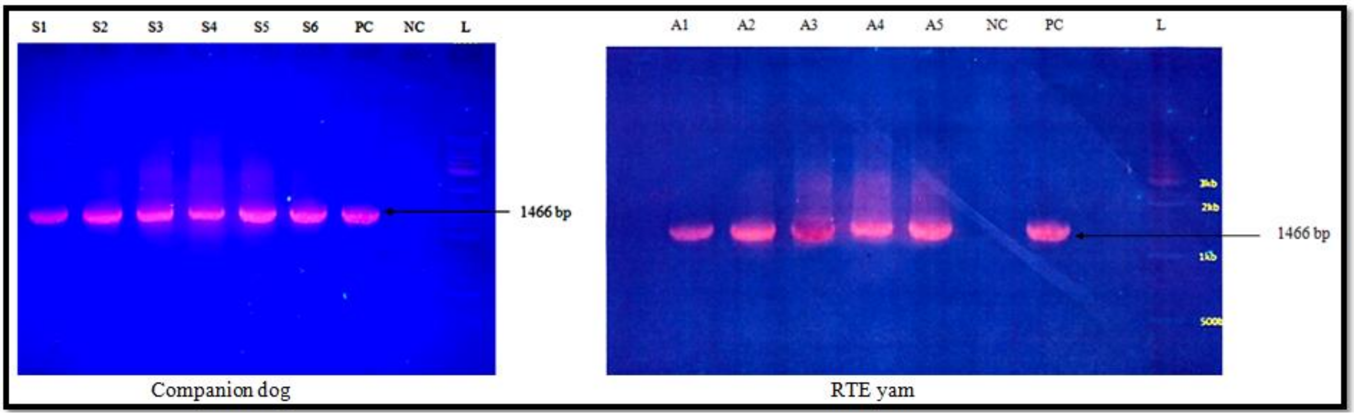

Figure 1: Gel electrophoresis of amplified 16S rRNA genes obtained from *S. aureus* isolated from the companion dogs and ready-to-eat yam samples

Lanes S1 to S6, as well as lanes A1 to A5, were positive samples for 16S rRNA genes obtained from suspected Staphylococcus species isolated from the companion dogs and ready-to-eat yam samples; Lane PC is the positive control (S. aureus ATCC 25923), while lane NC is the negative control (distilled water); Lane L is the molecular ladder (100 base ladder); Forward primer is 27F (AGAGTTTGATCMTGGCTCAG) and Reverse primer is 1492R (GGTTACCTTGTTACGACTT); Gel electrophoresis was performed with 2% agarose.

The data on the concentration and prevalence of *S. aureus* and its enterotoxigenic strains in companion dogs are detailed in Table 4. During the rainy season, one hundred and fifty (150) presumed *S. aureus* colonies were isolated from MSA plates inoculated with samples from companion dogs in Delta State, and these colonies underwent both phenotypic and immunological testing. In the dry season, a total of 181 isolates were similarly tested. In both seasons, 20 presumed *S. aureus* isolates during the rainy season and 67 during the dry season were confirmed as *S. aureus*. Among these confirmed isolates, 14 out of 20 during the rainy season and 31 out of 67 during the dry season produced staphylococcal enterotoxins. In Edo State, 27 isolates were confirmed as *S. aureus* from a total of 138 presumed isolates examined in the dry season, while 85 out of 192 presumed isolates during the rainy season yielded confirmed *S. aureus*. Besides, during the dry and rainy seasons, 16 and 57 confirmed *S. aureus* isolates, respectively, were found to produce staphylococcal enterotoxins. The mean concentrations of enterotoxin-producing *S. aureus* in companion dogs from Delta State were recorded as 0.21 ± 0.02 $\log_{10}$ CFU cm^{-2} during the dry season and 0.69 ± 0.62 $\log_{10}$ CFU cm^{-2} during the rainy season. Similarly, in Edo State, these concentrations were 0.25 ± 0.01 and 1.25 ± 1.09 $\log_{10}$ CFU cm^{-2} for the dry and rainy seasons, respectively. The data regarding the concentrations of *S. aureus* and its enterotoxigenic strains in the yam samples are summarized in Table 5. In Delta State, among the 181 presumed isolates subjected to testing, 25 isolates were confirmed to be *S. aureus*. Of these, 18 confirmed isolates were found to produce staphylococcal enterotoxins during the dry season. In the rainy season, 201 presumed *S. aureus* colonies were examined, resulting in 96 confirmed *S. aureus* isolates, with 86 of these producing enterotoxins. Similarly, in Edo State, out of 185 presumed *S. aureus* isolates tested during the dry season, 28 isolates were confirmed as *S. aureus*, with 17 confirmed isolates producing enterotoxins. During the rainy season, 146 isolates out of 207 presumed *S. aureus* were confirmed, and 135 of these confirmed isolates were found to produce enterotoxins. The levels of enterotoxin-producing *S. aureus* found in yam samples from Delta State were recorded as 0.23 ± 0.02 $\log_{10}$ CFU g^{-1} during the dry season and increased to 1.76 ± 1.58 $\log_{10}$ CFU g^{-1} in the rainy season. In Edo State, the concentrations were reported as 0.22 ± 0.01 $\log_{10}$ CFU g^{-1} in the dry season, rising to 2.97 ± 2.59 $\log_{10}$ CFU g^{-1} during the rainy season.

The prevalence of enterotoxins A, B, and C was reported at 55.88%, 27.01%, and 17.11%, respectively, in isolates of *S. aureus* capable of producing enterotoxins, obtained from companion dogs and yam samples. Notably, enterotoxin D was absent in all the isolates that tested positive for enterotoxin production. Co-production of enterotoxins A and B was observed in 17.91% of these isolates, while 3.74% produced both A and C simultaneously. Besides, a small proportion, amounting to 2.67% of the isolates produced all three enterotoxins, A, B, and C, concurrently.

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Table 4: Concentrations of *S. aureus* and its enterotoxigenic strains in companion dogs

Sampling Locations	Period of Sampling	Counts of presumed *S. aureus* (*CPMS*)			Counts of confirmed *S. aureus* (*CMS*)		Counts of enterotoxin-producing *S. aureus* (*CES*)		
		Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	95% CI Log_{10} CFU cm^{-2} (N = 35)	Relative occurrence of *S. aureus*	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	Relative occurrence of enterotoxin - Producing *S. aureus*	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)
Delta State, Nigeria	January – March 2020 (Dry season)	2.20 ± 0.23	1.75 – 2.65	20/150	0.29 ± 0.03	0.23 – 0.35	14/150	0.21 ± 0.02	0.17 – 0.25
	July – September 2020 (Rainy season)	4.00 ± 3.59	0.00 – 11.04	67/181	1.48 ± 1.33	0.00 – 4.08	13/181	0.69 ± 0.62	0.00 – 1.90
Edo State, Nigeria	January – March 2020 (Dry season)	2.17 ± 0.10	1.98 – 2.37	27/138	0.43 ± 0.02	0.39 – 0.47	16/138	0.25 ± 0.01	0.23 – 0.27
	July – October 2020 (Rainy season)	4.21 ± 3.68	0.00 – 11.42	85/192	1.86 ± 1.63	0.00 – 5.05	57/192	1.25 ± 1.09	0.00 – 3.39

Table 5: Concentrations of *S. aureus* and its enterotoxigenic strains in the yam samples

Sampling Locations	Period of Sampling	Counts of presumed *S. aureus* (*CPMS*)			Counts of confirmed *S. aureus* (*CMS*)		Counts of enterotoxin-producing *S. aureus* (*CES*)		
		Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	95% CI Log_{10} CFU cm^{-2} (N = 35)	Relative occurrence of *S. aureus*	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	Relative occurrence of enterotoxin - Producing *S. aureus*	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)	Mean ± SE Log_{10} CFU cm^{-2} (N = 35)
Delta State, Nigeria	January – March 2020 (Dry season)	2.31 ± 0.24	1.84 – 2.78	25/181	0.71 ± 0.07	0.57 – 0.85	18/181	0.23 ± 0.02	0.19 – 0.27
	July – September 2020 (Rainy season)	4.12 ± 3.70	0.00 – 11.37	96/201	1.97 ± 1.77	0.00 – 5.44	86/201	1.76 ± 1.58	0.00 – 4.86
Edo State, Nigeria	January – March 2020 (Dry season)	2.39 ± 0.11	2.17 ± 2.61	28/185	0.36 ± 0.02	0.32 – 0.40	17/185	0.22 ± 0.01	0.20 – 0.24
	July – October 2020 (Rainy season)	4.55 ± 3.97	0.00 – 12.33	146/207	3.21 ± 2.80	0.00 – 8.70	135/207	2.97 ± 2.59	0.00 – 8.04

Note: CI: Confidence interval; SE: Standard error

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As presented in Table 5; during the dry season in Delta State, approximately 14.29% (5 out of 35) of the samples carried *S. aureus*, with 8.57% (3 out of 35) harboring enterotoxin-producing strains. In comparison, in Edo State, 20.00% (7 out of 35) of companion dogs carried *S. aureus*, and 11.43% (4 out of 35) carried enterotoxin-producing *S. aureus*.

During the rainy season, the prevalence increased, with 48.57% (17 out of 35) of dogs in Delta State exhibiting *S. aureus*, and 22.86% (8 out of 35) carrying enterotoxin-producing strains. In Edo State, 60.00% (21 out of 35) of dogs carried *S. aureus*, while 40.00% (14 out of 35) carried enterotoxin-producing *S. aureus*. Regarding yam samples during the dry season, 17.14% (6 out of 35) in Delta State and 20.00% (7 out of 35) in Edo State showed contamination with *S. aureus*. Contamination with enterotoxin-producing strains in yam samples was observed at 14.29% (5 out of 35) in Delta State and 11.43% (4 out of 35) in Edo State. In the rainy season, contamination levels rose greatly, with 68.57% (24 out of 35) of yam samples carrying *S. aureus*, and 100% (35 out of 35) in Edo State. Similarly, enterotoxin-producing *S. aureus* was found in 62.86% (22 out of 35) of samples from Delta State and in 97.14% (34 out of 35) from Edo State.

The initial prevalence and concentration of each unit within the yam samples were set at zero (0) and less than or equal to 1.00 CFU per gram (0.00 $\log_{10}$ CFU/g), respectively. This is because each unit of the yam samples used for process modeling was sterilized at the outset prior to contamination by the companion dogs. Based on the estimated likelihood of contamination of each yam unit by enterotoxin-producing *S. aureus* derived from experimental analysis—values of 0.1429 and 0.1143 were assigned for the risk scenarios in Delta and Edo States during the dry season.

Conversely, during the rainy season, the assigned values increased to 0.6286 and 0.9714, respectively. The uncertainties associated with these contamination likelihoods were represented by a Uniform probability distribution, with a minimum value of zero (0) and a maximum of one (1). Using an 'additive increase' process type, the variability in the amount of enterotoxin-producing *S. aureus* added to each yam unit was characterized by a Triangular probability distribution.

The parameters included non-normally distributed minimum amounts (1.40 $\log_{10}$ CFU for both Delta and Edo States across seasons), modal amounts (1.40 $\log_{10}$ CFU for both states across seasons), and maximum amounts specifically, 4.09 $\log_{10}$ CFU for Delta and 4.14 $\log_{10}$ CFU for Edo during the dry season; and 8.89 $\log_{10}$ CFU for Delta and 9.32 $\log_{10}$ CFU for Edo during the rainy season derived by multiplying the maximum concentrations (2.69 $\log_{10}$ CFU/g for Delta and 2.74 $\log_{10}$ CFU/g for Edo during the dry season; 7.49 and 7.92 $\log_{10}$ CFU/g for Delta and Edo during the rainy season, respectively) by the sample mass (25 grams for both Delta and Edo States), as obtained through experimental procedures. In modeling the consumption, the weights of the general population (ages 2 to 75) and the serving size of the yam samples were incorporated. Population body weight data was based on published figures by Ayoola et al. (2009), Edelu et al. (2020), and field survey results. Variability in body weight was represented via a Triangular distribution with minimum (14.10 kg), modal (77.40 kg), and maximum (79.30 kg) values.

According to data from Sanusi and Olurin (2012), a fixed serving size of 68 grams was used to calculate the dose of enterotoxin-producing *S. aureus* per serving. An annual frequency of one eating occasion was assumed, with no impact on the risk assessment. According to data published by the Canadian Pathogen Regulation Directorate in 2010, a concentration of 10^5 CFU/g of *S. aureus* was used to estimate the infectious dose for enterotoxin-producing strains of the bacterium. Based on this, the infectious dose was approximated at 6,800,000 CFU when considering a standard serving size of 68 grams of yam. Since the r-parameter was defined as the reciprocal of the infectious dose, it was calculated to be approximately 0.00000015. This value was then incorporated into the software to generate an exponential dose-response curve, which is depicted in Figure 2.

The results of the risk assessment were derived from variables entered into the FDA-iRisk software. Assuming a population of one million individuals in Delta and Edo States consumed portions of the contaminated yam (contamination originating from colonized companion dogs during the dry season), approximately 129 people in Delta State and 139 in Edo State are likely to develop staphylococcal food poisoning.

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This translates to roughly 1 case per 10,000 servings of the yam in each state. During the rainy season, among the same population, an estimated 702 individuals in Delta State and 831 in Edo State would most probably contract staphylococcal food poisoning, corresponding to about 702 cases per 10,000 servings in Delta State and 831 cases per 10,000 servings in Edo State.

Discussion

The level of cleanliness in shelters or homes where companion dogs are kept greatly influences bacterial cross-contamination mediated by these animals (Song *et al.*, 2013). This study found that the fur of companion dogs served as a reservoir for *S. aureus* and its strains capable of producing enterotoxins, especially during the rainy season. Seasonal changes may contribute to this prevalence, likely due to the increased presence of *S. aureus* and its enterotoxigenic strains during periods of heavy rain. In addition, the study extensively analyzed the interaction between humans and dogs. A substantial proportion of dog owners reported sharing their kitchens (55.00%), bedrooms (46.00%), and household furniture (66.00%) with their pets. Several reports have documented zoonotic infections caused by *S. aureus* (Manian, 2003; Vincze *et al.*, 2010; van Duijkeren *et al.*, 2011).

The chi-square test of independence indicated a significant association ($p < 0.05$; Chi-Square = 146.69) between cohabitation with dogs and the risk of acquiring zoonotic infections, suggesting a potentially high likelihood of transmission of staphylococcal bacteria or enterotoxins from dogs to humans or vice versa, especially if either party is carrying *S. aureus*. In this study, the prevalence of enterotoxin-producing S. aureus in companion dogs ranged from 7.18 to 29.69% and from 9.19 to 71.89% in the contaminated RTE bread. Abdel-moein and Samir (2011) reported a 10% prevalence rate of enterotoxigenic S. aureus in companion dogs from Egypt. This prevalence rate was within the range found in this Nigerian study. Thus, the companion dogs could be regarded as an essential reservoir for enterotoxin-producing S. aureus. The relatively high prevalence of enterotoxin-producing S. aureus in this study, particularly in the RTE bread, indicates their importance for active infection in humans.

The most prevalent staphylococcal enterotoxin (SE) type produced by isolates examined in this study was SE type A. Companion dogs are often in intimate contact with their owners. So isolation of enterotoxin-producing S. aureus from these companion dogs suggests the possibility of zoonotic transmission of such strains to human contacts. The transmission could be by direct contacts with the infected animals or indirectly from contaminated foods. This indirect contamination is often considered a vital potential source for food contamination and is regarded as the cornerstone in the initiation of household staphylococcal food poisoning outbreaks (Colombari et al., 2007). A peculiar attention should be paid to SE type A that is produced by isolates recovered from the companion dogs, as it is often termed to be the common cause of staphylococcal food poisoning worldwide (Balban and Rasooly, 2000).

The predicted risk of staphylococcal food poisoning from consuming yam contaminated with enterotoxin-producing *S. aureus* carried by colonized companion dogs was notably higher in Edo State compared to Delta State. The risk was particularly pronounced in Edo State during the rainy season, likely due to unrestricted contact between residents, food, and colonized dogs. To our knowledge, this is possibly the first effort to quantify the potential risk of staphylococcal food poisoning mediated by companion dogs in Nigeria, given the absence of published data for comparison. Globally, published data on this specific pathway are also lacking, although there are reports of staphylococcal food poisoning from other sources (Chiang *et al.*, 2008; Ostyn *et al.*, 2010; Johler *et al.*, 2013; Kirk *et al.*, 2014; Park *et al.*, 2015; Van Cauteren *et al.*, 2017).

Conclusion

The current study indicates a substantial potential for the transmission of staphylococcal bacteria and enterotoxins between dogs and humans, emphasizing a major link between cohabitation with dogs and the risk of zoonotic infections. These findings are further supported by the considerable danger of staphylococcal food poisoning associated with pet dogs in Delta and Edo States, particularly during the rainy season, emphasizing needing awareness and preventive measures.

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