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REVIEW

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Update on prevalence and antimicrobial resistance of *Staphylococcus aureus* and *Pseudomonas aeruginosa* isolated from diabetic foot ulcers in Africa: a systematic review and meta-analysis

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Abstract

Background Diabetes mellitus is increasing in Africa, and diabetes-related amputations exacerbated by diabetic foot infection are also prevalent with *Staphylococcus aureus* and *Pseudomonas aeruginosa* two priority pathogens playing key roles. Understanding the local epidemiology and antimicrobial resistance profiles of these dominant pathogens is crucial for appropriate antibiotic therapy.

Main body of abstract This systematic review and meta-analysis aim to contribute valuable insights that can guide the management of diabetic foot ulcer-related infections in Africa by comprehensively analyzing the available literature on the prevalence and antimicrobial resistance profiles of *Staphylococcus aureus* and *Pseudomonas aeruginosa* in infected diabetic foot ulcers across Africa. We conducted a continent-based literature search utilizing PubMed and Scopus databases on June 11th, 2023, to identify studies conducted in Africa among persons with diabetic foot ulcers that reported isolating bacteria from the foot ulcers. The main concepts related to this research, "diabetic foot ulcers", "diabetic foot infections", "bacteria" and "Africa" were expanded with their synonyms and combined using Boolean operators (AND, OR) to formulate the final search query. The selection and inclusion of studies followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA). Our review revealed that approximately 4124 bacteria have been isolated from diabetic foot ulcers across 13 African countries. *Staphylococcus aureus* is the dominant species with a random effect pooled prevalence of 19.9% (95%CI: [16.19–23.84%]; $I^2 = 88.56\%$ [82.26–92.62%]) followed by *Pseudomonas aeruginosa* with 11.8% (95%CI: [8.67–15.23%]; $I^2 = 89.95\%$ [84.67–93.41%]). Methicillin-resistant *Staphylococcus aureus* (MRSA) pooled 12.9% (95%CI: [3.99–25.89%]; $I^2 = 95.47\%$ [93.68–96.75%]). Multidrug-resistant *S.aureus* and *P. aeruginosa* pooled prevalence is 26.4% (95%CI: [17.84–36.06%]; $I^2 = 71.16\%$ [49.34–83.58%]) and 41.8% (95%CI: [27.38–56.91%]; $I^2 = 78.48\%$ [60.80–88.18%]), respectively.

Short conclusion *Staphylococcus aureus* dominates diabetic foot ulcer (DFU) isolates in Africa contrary to the prevailing assertion about *Pseudomonas aeruginosa*. However, multidrug resistance among both species is high emphasizing the need for antimicrobial stewardship and utilization of other wound management protocols such as topical silver sulfadiazine (SSD) for the duo.

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Keywords Diabetic foot ulcers, Diabetic foot infections, Meta-analysis, *Staphylococcus aureus*, *Pseudomonas aeruginosa*

Background

Diabetes mellitus is a chronic metabolic disorder characterized by increased blood sugar resulting from the body's inability to secrete or use insulin (Gospin et al. 2017). It is a major global health concern, with the number of individuals affected rising steadily over the years (Abdul et al. 2020; Kotwas et al. 2021; Lin et al. 2020). According to the International Diabetes Federation (IDF), one in 10 adults is affected by diabetes worldwide. Africa has witnessed a substantial increase in the prevalence of diabetes, with an estimated 24 million adults living with the condition in 2021 (Team 2023). Diabetes-related complications significantly contribute to the morbidity and mortality associated with this disease, and one of the most devastating complications is diabetic foot ulcers (DFUs) (Akkus and Sert 2022; Wang et al. 2022;). Globally, the prevalence of DFUs stands at 6.3% (Adem et al. 2020). The burden of DFU in Africa (7.2%) is 1.3-fold that of Asia (5.5%), the most populous continent (Vahwere et al. 2023; Su et al. 2023).

Diabetic foot ulcers predispose individuals to severe and life-threatening infections (Ramirez-Acuña et al. 2019), which are further exacerbated by the emergence of multidrug-resistant bacteria, which undermine the effectiveness of antimicrobial treatments and result in worsened patient outcomes. A recent meta-analysis correlated the prevalence of gram-positive and gram-negative bacteria with Gross National Income (GNI), confirming earlier assertions that gram-positives dominate isolates among high-income countries and gram-negative isolates among upper/lower middle-income countries (Macdonald et al. 2021). Nevertheless, the study acknowledged the importance of local microbiological knowledge in guiding clinical practice. Among these bacterial pathogens, *Staphylococcus aureus* and *Pseudomonas aeruginosa* are two dominant species in DFU in Africa and beyond. The priority status of this pair with regard to antimicrobial resistance transcends geographical boundaries, underscoring the need for constant monitoring of their presence and antimicrobial susceptibility profiles. According to Breidenstein et al., (2011), with regard to *Pseudomonas*, all roads lead to resistance.

Several studies across Africa have highlighted the dominance of *Staphylococcus aureus* and *Pseudomonas aeruginosa* in diabetic foot ulcers, yet, a comprehensive study that synthesizes African studies to present their prevalence and antimicrobial resistance profiles is currently lacking.

Methods

Search strategy

We searched two bibliographic databases, PubMed and Scopus, on June 11th, 2023, to identify African studies which reported isolating bacteria from foot ulcers of persons with diabetes. We formulated our search query by combining key concepts including "diabetic foot ulcers," diabetic foot infections" and "bacteria" expanded with "bacterial isolates" OR "Cultures", "Swabs", "Pathogens" and "Africa" using the Boolean operators (AND, OR). Africa was expanded to include all 54 countries. We also searched for gray literature and other studies which might have been published in journals not indexed in the databases we searched earlier using keywords on Google scholar. The search query is presented as Additional file 1. No protocol was published for this study (Additional file 2).

Study selection criteria

The inclusion criteria for the reviewed studies included: (i) studies must be conducted in Africa among patients with diabetic foot ulcers (ii) studies must report bacterial isolation, including *Staphylococcus aureus* and *Pseudomonas aeruginosa*, from diabetic foot ulcers. (iii) Studies must have recruited at least 10 participants. Studies that did not meet the inclusion criteria were excluded. The exclusion criteria included: (i) studies lacking evidence of primary isolation of bacteria, (ii) meta-analysis, (iii) review articles, (iv) case reports with less than 10 respondents and (iv) studies without accessible full texts. The selection of eligible studies followed the Preferred Reporting Items for Systematic Reviews and Meta-analysis (Stroup et al. 2000) (Fig. 1).

Data extraction and critical appraisal

The search query was formulated and agreed upon by all authors (MD, MO, EE and EA). Two authors (MD and MO) independently conducted the literature search, removed duplicates and screened titles and abstracts. The authors also accessed eligible studies for full text screening. Using a standardized authors' developed Microsoft Excel (2019) spreadsheet, the authors (MD and EE) extracted and added data relevant to this study from studies which have met the inclusion criteria into columns labeled as follows: author name, study title, year of publication, country, sample size (number of people recruited into the study), the total number of bacteria isolated, *Staphylococcus* species

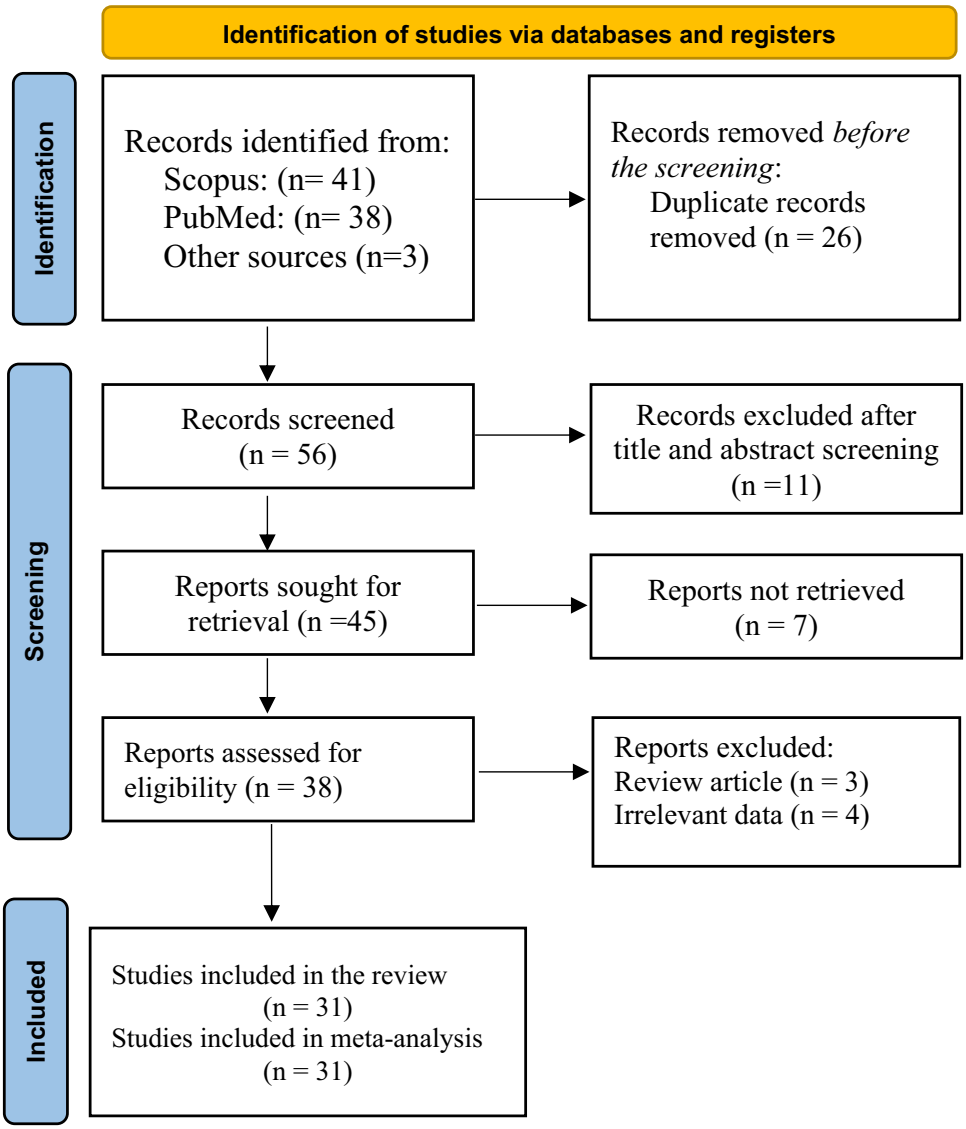

Fig. 1 PRISMA study selection framework

isolated, *Pseudomonas aeruginosa* isolated, period of study, specimen type, isolation method, study design, patient setting (in- or outpatients), antibiotics used and antibiotic resistance. Critical appraisal to assess the quality and risk of bias of included studies was achieved using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for studies reporting prevalence data (Additional file 3) adapted from Macdonald et al. (2021). Publication bias was assessed using funnel plots (Additional file 4). Two authors (MD and EA) independently performed the appraisals; whenever there was a discrepancy, it was resolved by consensus.

Statistical analysis

Using the random effect analysis model, we computed the pooled prevalence of *Staphylococcus aureus,* Methicillin-resistant *Staphylococcus aureus* (MRSA), *Pseudomonas aeruginosa* and multidrug resistance at 95% confidence intervals (CI). We used the I^2 statistic to assess study heterogeneity and interpreted as low, moderate or high the values (≤25%), (25–75%), and (≥75%), respectively (Higgins et al. 2003). All meta-analyses were performed using MedCalc® Statistical Software version 22.006.

Results

Study selection and characteristics

We systematically searched two databases and retrieved 79 studies. Three studies were found from other sources making a total of 82 studies. Twenty-six (26) duplicates were removed, and 56 studies were subjected to title and abstract screening. Eleven titles and abstracts were found to be ineligible and excluded. The remaining 45, which passed title and abstract screening, were further screened for all components of the inclusion criteria. At this stage, three review articles, four studies lacking relevant data, and seven studies that needed to present their data clearly were excluded. Figure 1 shows the study selection process. Critical appraisal of the eligible studies observed discrepancies in reporting, especially in studies that used multiple specimens from individual respondents yet presented combined frequencies of various species isolated; however, this was not considered a ground for exclusion.

Thirty-one studies made the inclusion criteria and were spread across thirteen African countries with different regions of the continent represented. Most studies (93.5%) adopted prospective study designs, and the rest were retrospective. More than a third (70.9%; $n=22$) of the studies were published between 2015 and 2023. The earliest work that studied the bacteriological profile of diabetic foot ulcers on the continent was conducted in Nigeria between 2001 and 2002 and published in 2005. The most frequent study location on the African continent was Egypt, with seven ($n=7$) publications, followed by Nigeria ($n=6$), Tanzania, Uganda, Algeria, Tunisia, Sudan, Ethiopia, and Cameroun, with two publications each. On a regional basis, almost half ($n=14$) of studies reporting the bacterial profile of DFU were conducted in northern Africa. All study characteristics are presented as Additional file 2.

In the study population and patient setting, most studies ($n=11$) recruited outpatients, and another 25% ($n=8$) recruited both inpatients and outpatients. The remaining studies ($n=12$) had half recruiting inpatients, while the remaining half did not report whether its respondents were inpatients, outpatients, or both. Overall, the study participants were diabetic patients with diabetic foot ulcers.

The sampling of the diabetic foot ulcers for microbiological investigation involved different specimens ranging from swabs, aspirates, and biopsies. Some studies collected one type of sample, while others collected different types of samples. Almost half ($n=15$), constituting 48.8% of the studies, reported using swab samples and did not mention whether they were superficial or deep swabs. Another 22.8% ($n=7$) used deep wound swabs. Other samples used include biopsy ($n=3$), biopsy and aspirate ($n=1$), deep swab and aspirate ($n=1$), superficial swab and deep swab ($n=1$), swab and biopsy ($n=1$) and deep swab, biopsy and aspirate ($n=1$). One study did not report the sample used for microbiological investigation.

The thirty-one studies pooled 3761 respondents and isolated 4124 bacteria spread across several species. *Staphylococci* species isolated was 1063, constituting 25.8% of the cumulative DFU bacterial isolates on the continent. *Staphylococcus aureus* was the predominant gram-positive bacteria and *Staphylococcus* species, accounting for 79.2% of all *Staphylococcus* species and 20.6% of overall bacterial isolates. MRSA ($n=161$) constituted 15.1%% and is the second most frequent *Staphylococcus* species. *Pseudomonas aeruginosa* on the other hand dominated the gram-negative isolates ($n=595$) and constituted 14.4% of the total bacterial isolates.

Prevalence of *Staphylococcus aureus* and *Pseudomonas aeruginosa* in DFU across Africa

Using the records of the 31 studies, we computed the meta-analytic prevalence of *Staphylococcus aureus* and *Pseudomonas aeruginosa* isolated from 3761 diabetes patients with foot ulcers. The continental pooled prevalence of *Staphylococcus aureus* and MRSA isolated from DFU at 95%CI is 20.4% (19.19–21.68%) and 3.9% (3.33–4.54%), while *P. aeruginosa* is 11.8% (8.67–15.23%).

Our meta-analysis shows that *S. aureus* is the dominant DFU isolate in Africa followed by the gram-negative bacteria, *Pseudomonas aeruginosa*; however, the presence of MRSA is particularly worrisome. MRSA was predominantly higher in North Africa than Sub-Saharan Africa with almost half ($n=73$) of MRSA isolated in Algeria, 14.4% (11.44–17.73%), followed by Ethiopia at 11.1% (7.36–15.79%). DFUs in Ghana pooled the highest prevalence of *P. aeruginosa*; 19.79% (12.36–29.17%) followed by Sudan and Uganda. Table 1 and the forest plots in Figs. 2, 3 show the meta-analytic pooled prevalence of *S. aureus* and *P. aeruginosa* isolated from diabetic foot ulcers across Africa.

Distribution of *Staphylococcus aureus*, MRSA and *Pseudomonas aeruginosa* according to study characteristics

We conducted a subgroup meta-analysis by study characteristics, including patient setting, clinical sample, study period and method of isolation. Table 2 summarizes the sub group meta-analytic prevalence of *Pseudomonas aeruginosa*, *S. aureus* and MRSA by different study characteristics.

Regarding the patient setting, we observed that studies with samples from outpatients pooled a significant amount of *S. aureus* and *P. aeruginosa* 23.2% (20.44–26.14%) and 18.97% (16.42–21.73%), respectively, compared to inpatients. Interestingly, no single

Table 1 National prevalence of S.aureus, MRSA and Pseudomonas aeruginosa in DFU across Africa

Country	Total bacterial isolates	Pooled prevalence (%) 95% CI					
		S. aureus	I^2 (*P*-value)	MRSA	I^2 (*P*-value)	*P. aeruginosa*	I^2 (*P*-value)
Algeria	508	28.5 (24.65–32.69)	88.56 (82.26 92.62)	14.4 (11.44–17.73)	95.64 (82.26–92.62)	11.61 (8.96–14.73)	89.95 (84.67–93.41)
Burkina Faso	71	32.4 (21.76–44.55)		0.0 (0.00–5.06)		2.82 (0.34–9.81)	
Cameroon	255	13.3 (9.41–18.13)		0.0 (0.00–1.44)		10.98 (7.42–15.48)	
Egypt	566	12.2 (9.61–15.17)		2.5 (1.36–4.12)		16.61 (13.63–19.94)	
Ethiopia	235	27.2 (21.65–33.40)		11.1 (7.36–15.79)		16.17 (11.70–21.51)	
Ghana	96	19.8 (12.36–29.17)		6.3 (2.33–13.11)		19.79 (12.36–29.17)	
Kenya	80	17.5 (9.91–27.62)		0.0 (0.00–4.51)		7.50 (2.80–15.61)	
Morocco	307	13.7 (10.04–18.04)		0.7 (0.08–2.33)		3.90 (2.04–6.73)	
Nigeria	991	21.1 (18.59–23.76)		0.0 (0.00–0.37)		18.37 (16.00–20.92)	
Sudan	606	24.9 (21.52–28.56)		4.6 (3.09–6.62)		19.31 (16.24–22.68)	
Tanzania	146	8.2 (4.32–13.92)		0.0 (0.00–2.50)		4.80 (1.94–9.63)	
Tunisia	141	26.2 (19.20–34.31)		4.3 (1.58–9.03)		5.67 (2.48–10.87)	
Uganda	122	18.9 (12.34–26.93)		4.9 (1.83–10.40)		18.85 (12.34–26.93)	

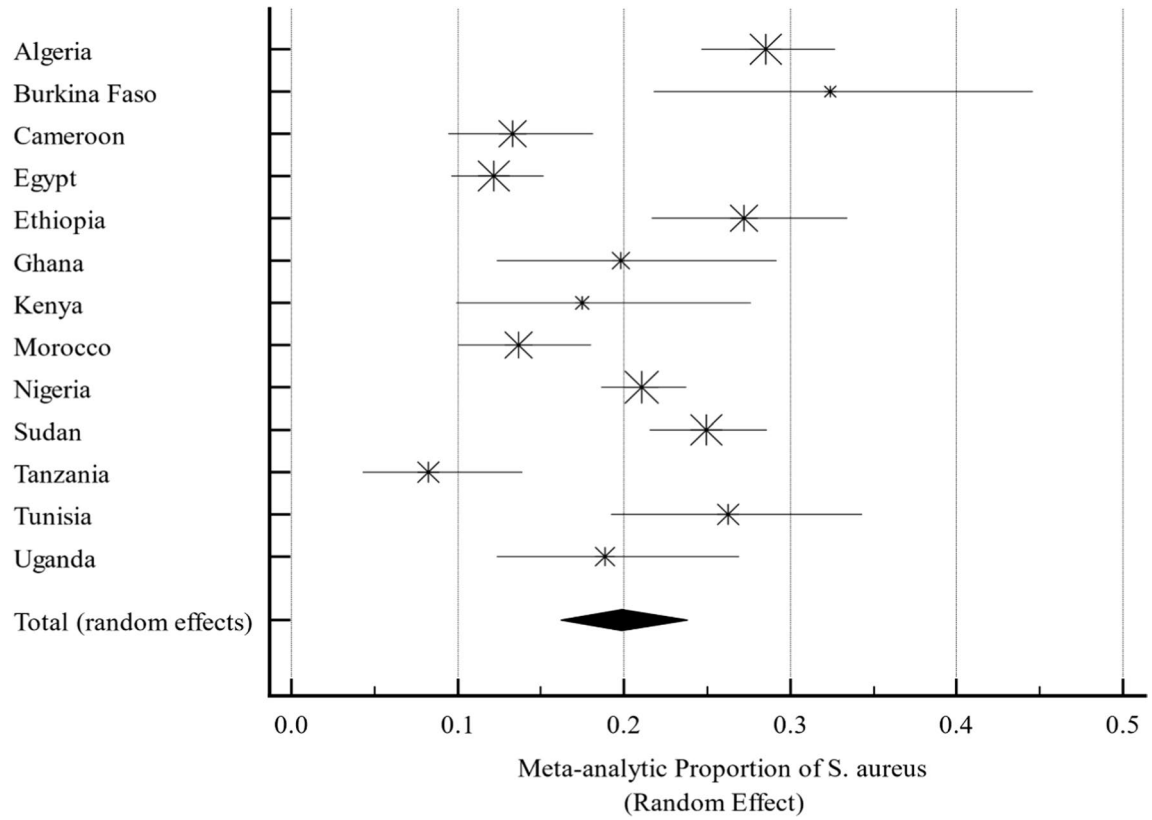

Fig. 2 Forest plot of proportion of DFU *Staphylococcus aureus* across Africa

MRSA isolated came from outpatients, but inpatients pooled 6.6% (5.28–8.07%) and highlighted the importance of infection control measures and surveillance within healthcare facilities to prevent and manage MRSA infections among hospitalized patients.

Over the years, there have been debates on the best sample for microbiological investigation of diabetic foot

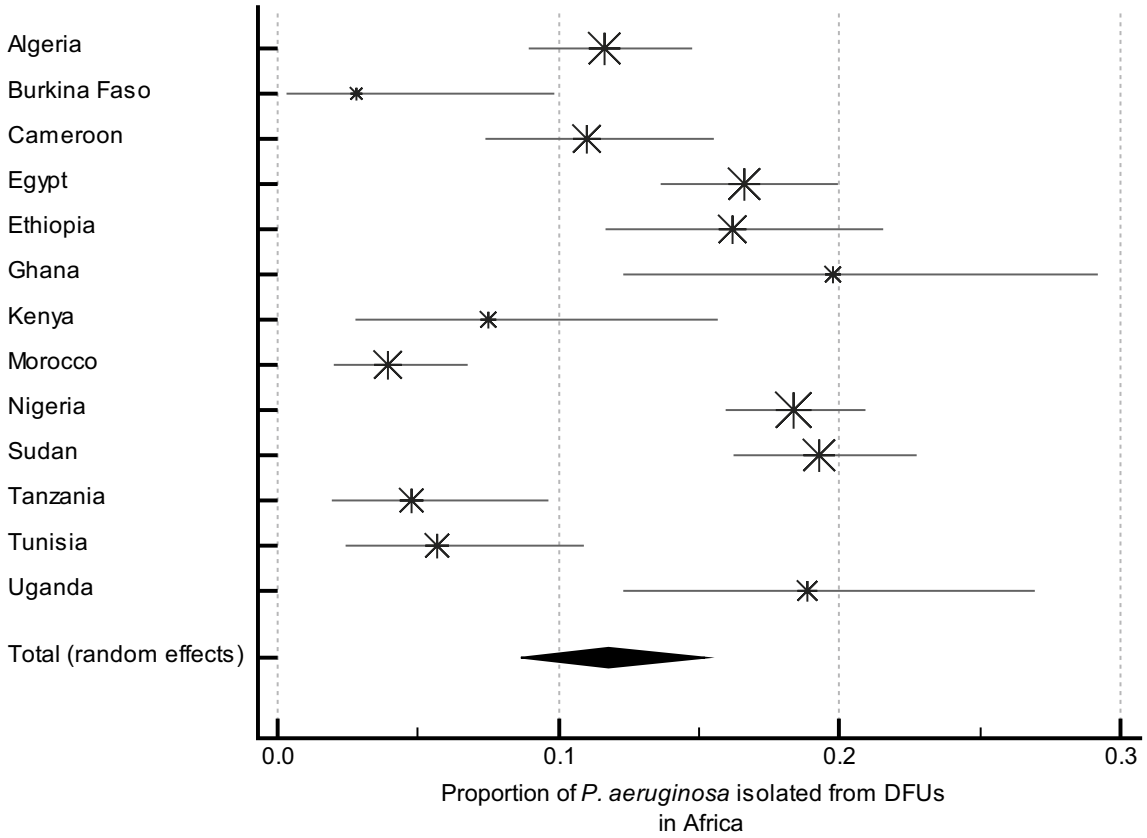

Fig. 3 Forest plot of meta-analytic prevalence of *P. aeruginosa* isolated from DFUs across Africa

ulcers. While swabs have been widely used, literature has reported biopsies as a gold standard.

Antimicrobial resistance

On antibiotic resistance, 13 and 10 studies with clear presentation of the antimicrobial susceptibility profile for *Staphylococcus aureus* and *Pseudomonas aeruginosa*, respectively, were analyzed. From these studies, the frequently used antibiotics included Imipenem, Meropenem, Cefepime, Cefixime, Cefuroxime, Ceftazidine, Cephalexin, Amoxicillin, Ticaracillin, Cotrimoxazole, Amikacin, Gentamicin, Ciprofloxacin, Doxycycline, Tetracycline, Levofloxacin, Trimethoprim, Chloramphenicol, Ceftriaxone, Ampicillin, Augmentin, Cefoxitin, Erythromycin, Vancomycin, Linezolid, Rifampicin, Clindamycin, Oxacillin and Penicillin G.

Out of the 331 *S. aureus* isolates from these 13 studies, multidrug resistance is 24% ($n=80$) and almost half ($n=165$) were resistant to Penicillin G. Resistance to Erythromycin, Tetracycline and Gentamicin was also high ([39%, $n=129$], [33%, $n=109$] and [27.5%, $n=91$]), respectively. On the other hand, multidrug-resistant *Pseudomonas aeruginosa* constituted 32.7% ($n=69$) with remarkable resistance to ciprofloxacin (29.9%, $n=63$) and Ceftazidine (30.3%, $n=64$). Figure 4 presents the prevalence of *Staphylococcus aureus* and *P. aeruginosa*-resistant DFU isolates against the commonly used antibiotics. Also, Table 3 and Figs. 5, 6 present the meta-analytic prevalence and forest plots of multidrug-resistant *Staphylococcus aureus* and *Pseudomonas aeruginosa.*

Discussion

Infected diabetic foot ulcers are mostly polymicrobial with predominantly bacteria (Dunyach-Remy et al. 2016). A recent meta-analysis on the microbiology of diabetic foot infections concludes that *Staphylococcus aureus* is the predominant pathogen isolated from infected ulcers (Macdonald et al. 2021). The meta-analysis further reported a correlation between Gross National Income and the prevalence of gram-positive or gram-negative bacteria in infected foot ulcers. It affirmed the assertion that gram-positive bacteria are higher in infected diabetic foot ulcers of patients from more developed nations than those in lower- and middle-income countries. Our meta-analysis observed that contrary to popular assertions, *Staphylococcus aureus* is the dominant DFU isolate in Africa ahead of *Pseudomonas aeruginosa*. The dominance of *Staphylococcus aureus* in our study has been

Table 2 Meta-analytic prevalence of P. aeruginosa, S. aureus and MRSA isolated from DFU Africa according to Study Characteristics

Study characteristics	*P. aeruginosa*	Pooled prevalence (95% CI)				
		I^2 (*P*-value)	*S. aureus*	I^2 (*P*-value)	*MRSA*	I^2 (*P*-value)
Patient setting						
Inpatient	12.61 (10.5–14.54)	98.1 (96.7–98.8)	22.8 (20.55–25.20)	97.4	6.6 (5.28–8.07)	97.9
Outpatient	18.97 (16.42–21.73)		23.2 (20.44–26.14)		0.0 (0.00–0.421)	
Both	8.13 (6.79–9.64)		12.6 (10.93–14.36)		2.9 (2.16–3.95)	
Not reported	30.98 (26.82–35.39)		33.5 (29.28–38.03)		6.8 (4.72–9.52)	
Clinical sample						
B	21.27 (17.97–24.86)	94.9 (88.4–95.5)	27.8 (24.12–31.65)	96.6 (95.0–97.6)	0.0 (0.00–0.65)	95.4 (93.1–96.9)
BA	9.17 (5.69–13.81)		15.6 (11.05–21.11)		0.0 (0.00–1.68)	
DSA	3.91 (2.04–6.73)		13.7 (10.04–18.04)		0.7 (0.08–2.33)	
DSAB	0.00 (0.00–21.80)		100 (78.19–100.00)		40 (16.34–67.71)	
DS	12.04 (10.1–14.18)		20.5 (18.06–23.08)		2.5 (1.66–3.68)	
SSDS	7.237 (3.69–12.58)		13.2 (8.23–19.59)		0.0 (0.00–2.39)	
SB	11.24 (7.00–16.82)		0.0 (0.00–2.05)		7.9 (4.37–12.84)	
S	19.09 (17.00–21.32)		22.8 (20.56–25.16)		6.4 (5.18–7.90)	
NR	10.45 (7.39–14.23)		18.2 (14.22–22.77)		8.4 (5.63–11.85)	
Study period						
2002–2006	10.95 (7.57–15.19)	95.3 (91.7–97.4)	18.4 (14.04–23.39)	90.4 (80.6–95.3)	0.0 (0.00–1.29)	95.9 (92.8–97.6)
2007–2011	19.65 (16.32–23.34)		22.2 (18.66–25.98)		1.2 (0.43–2.49)	
2012–2016	8.24 (6.36–10.46)		20.7 (17.81–23.78)		9.9 (7.81–12.24)	
2017–2021	13.44 (12.05–14.93)		18.0 (16.46–19.71)		3.4 (2.71–4.27)	
Not reported	28.22 (23.66–33.14)		33.4 (28.60–38.52)		1.6 (0.61–3.54)	
Isolation method						
Culture	15.55 (14.32–16.83)	89.2 (70.4–96.0)	22.6 (21.15–24.03)	97.4 (94.8–98.7)	3.6 (2.99–4.29)	52.8 (0.00–86.5)
Culture& PCR	10.08 (6.689–14.42)		5.4 (2.99–8.94)		5.4 (2.99–8.94)	
Not reported	9.82 (7.49–12.59)		14.6 (11.82–17.85)		5.0 (3.35–7.15)	

B Biopsy, *S* Swabs, *SDS* Superficial and Deep Swab, *DS* Deep swab, *BA* Biopsy and Aspirate, *DSA* Deep Swab and Aspirate, *DSAB* Deep swab, aspirate and Biopsy, *SSDS* Superficial Swab and Deep Swab, *NR* Not reported, I^2: The percentage of variance in a meta-analysis that assesses study heterogeneity

corroborated by a recent meta-analysis of African studies by Wada et al., (2023). The concordance between their sub continental study and ours emphasizes the dominance of S. aureus in diabetic foot ulcers in Africa. This trend, however, is different in India and Lebanon where *Escherichia coli* is the dominant isolate (Kale et al. 2023; Su et al. 2023). The observed variations emphasize intercontinental disparity in the diversity of DFU infecting pathogens and underscores the role of gram-negative bacteria in DFU in Asia and the Middle East although *S.aureus* follows as the dominant gram-positive isolate. However, Wada et al. (2023) reported E. coli as the dominant gram-negative DFU isolate against the observed *Pseudomonas aeruginosa* in our study a variation that can partly be associated with the number of studies retrieved and included as well as subregional variations. The observed abundance of *E. coli* over *Pseudomonas* as reported in their study infers that *Pseudomonas aeruginosa* dominate gram-negative isolates in North African countries. Several inferences can be derived from these statistics; however, the virulence capability of these organisms should be prioritized especially that they registered high levels of multidrug resistance 24% and 32.7%, respectively, as corroborated by Wada et al. (2023). Across the continent, *Staphylococcus aureus* was significantly resistant to Penicillin G, Erythromycin, Tetracycline and Gentamycin, while *Pseudomonas* was observed to be resistant to Ceftazidine, Ciprofloxacin Amikacin, Levofloxacin and Gentamycin. The observed antibiotic resistance of these organisms is compounded by their notoriety for biofilm production. Their resulting bioactive compounds impair migration and proliferation of keratinocytes in chronic skin wounds and chronic tympanic membrane perforations resulting in worsened patient outcomes (Shettigar and Murali 2020).

Our systematic review and meta-analysis observe considerable susceptibility to Vancomycin ($n=150$) and Imipenem ($n=80$) by *Staphylococcus aureus* and *Pseudomonas aeruginosa*, respectively. However, considering the high levels of antibiotic resistance to frequently used

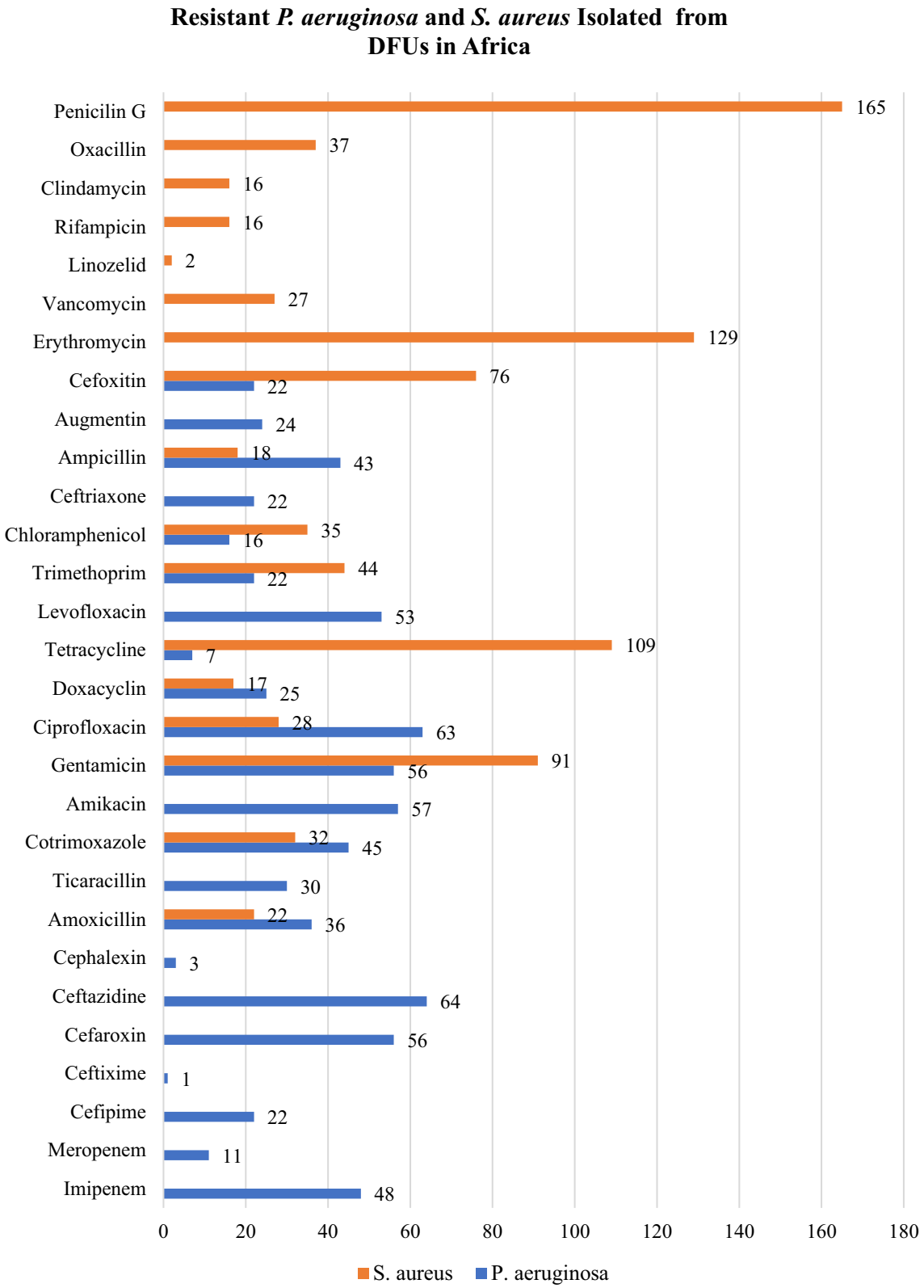

Fig. 4 Antibiotic-resistant *P. aeruginosa* and *S. aureus* isolated from diabetic foot ulcers in Africa

Table 3 Pooled prevalence of multidrug-resistant *S. aureus* and *P. aeruginosa*

Study	*S. aureus* Isolates	Proportion (%) 95% CI	I^2 (%) 95% CI	*P. aeruginosa* Isolates	Proportion (%) 95% CI	I^2 (%) 95% CI
Yakout et al	5	60.0 (14.66–94.73	71.7 (49.3–83.6)	43	16.28 (6.81–30.70)	78.5 (60.8–88.2)
Bouharkat et al	60	10.0 (3.76–20.51)		36	8.33 (1.75–22.47)	
Guira et al	23	17.39 (4.95–38.78)		2	100.0 (15.81–100.0)	
Arfaoui et al	15	53.33 (26.59–78.73)		–	–	
Anafo et al	19	26.32 (9.15–51.20)		–	–	
Mutonga et al	14	35.71 (12.76–64.86)		6	83.33 (35.88–99.58)	
Mashaly et al	18	33.33 (13.34–59.01)		6	83.33 (35.88–99.58)	
Anyim et al	11	36.36 (10.93–69.21)		–	–	
Atlaw et al	32	28.13 (13.75–46.75)		24	45.83 (25.55–67.18)	
Belefquih et al	42	14.29 (5.43–28.54)		27	33.33 (16.52–53.96)	
Pario et al	10	60.0 (26.24–87.85)		12	50.00 (21.09–78.91)	
Hamid et al	61	6.56 (1.82–15.95)		35	40.00 (23.87–57.89)	
Yefou et al	21	14.29 (3.05–36.34)		20	35.00 (15.39–59.22)	

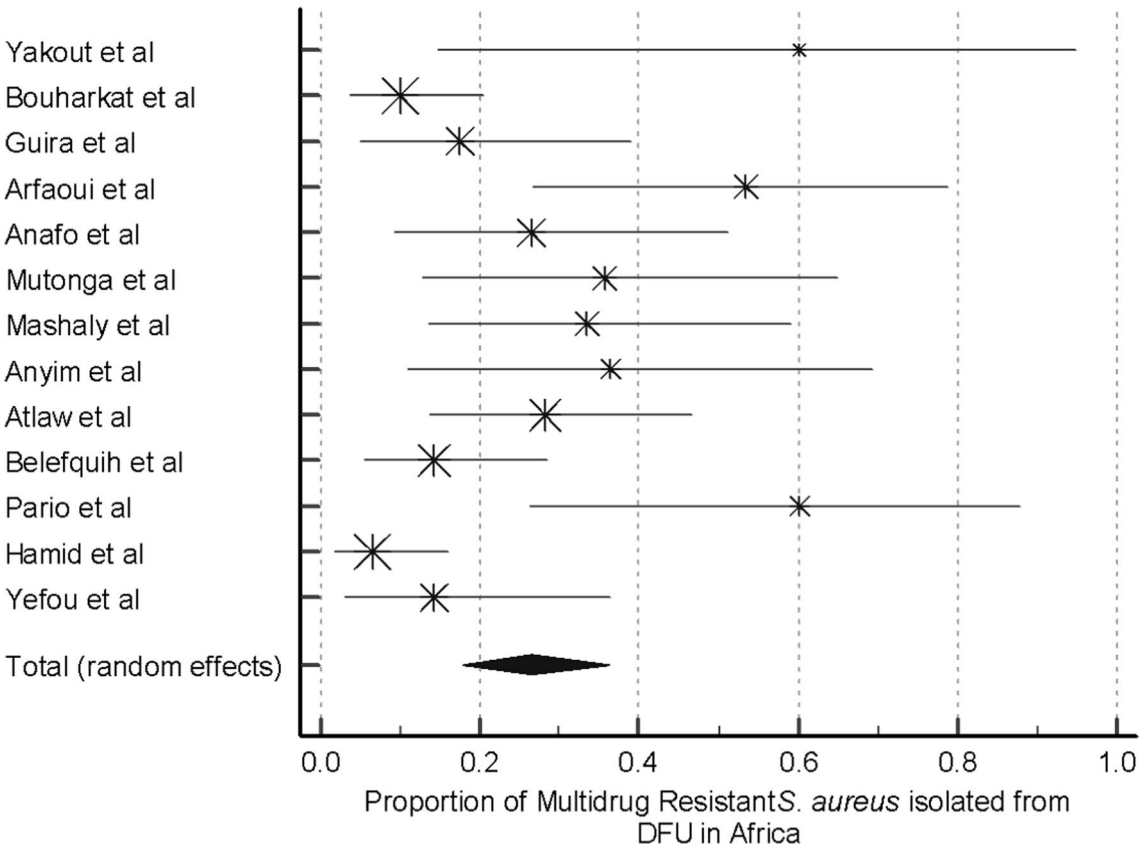

Fig. 5 Forest plot of the proportion of multidrug-resistant *Staphylococcus aureus* isolated from DFU in Africa

antibiotics, there is a need for the development of an empirical antibiotic treatment protocol in Africa as there currently is none, and the exploration of other managements modalities that will curb antimicrobial resistance while effectively treating infected DFUs such as energy based methods, dressings, growth factors, debridement, gene therapy, silver sulfadiazine (SSD) among others (Ramirez-Acuña et al. 2019; Di Domenico et al. 2020).

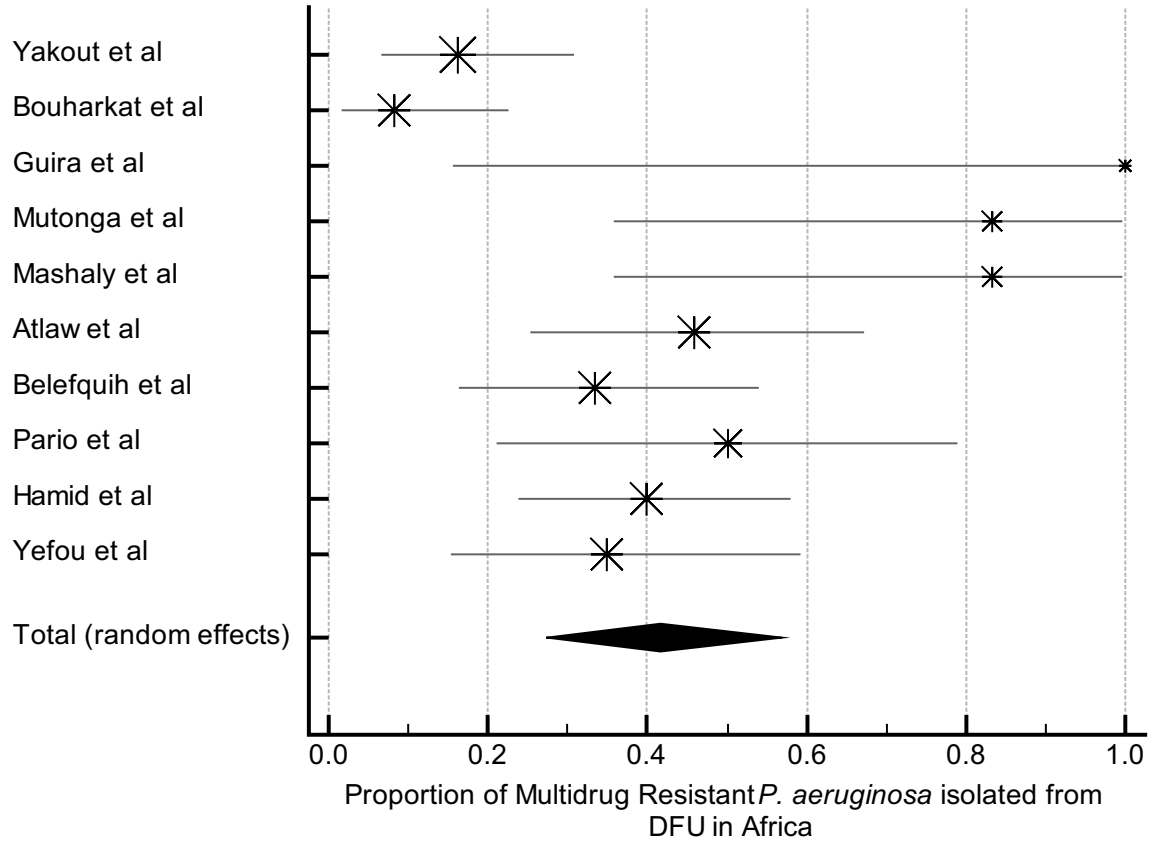

Fig. 6 Forest plot of the proportion of multidrug-resistant Pseudomonas aeruginosa isolated from DFU in Africa

To observe the trend in the prevalence of *Staphylococcus aureus* and *Pseudomonas aeruginosa*, we grouped the published studies into four periods: 2002–2006, 2007–2011, 2012–2016 and 2017–2021. The results suggest alternating prevalence with peak periods between 2007 and 2011 for *Staphylococcus aureus* and *Pseudomonas aeruginosa* and 2012–2016 for MRSA. There was a 1.2-fold increase in MRSA between 2002 and 2006, 8.25-fold increase in 2007–2011, and 2012–2016, after which there was a 6.5-fold decline in 2017–2021. The prevalence of *Pseudomonas aeruginosa* also suggests an increasing trend, a 1.8-fold increase between 2002–2006 and 2007–2011. Between 2017 and 2021, the prevalence of *S. aureus* declined by 1.2-fold while *Pseudomonas aeruginosa* increased by 1.6-fold. The observed downward and upward trend for these organisms brings one thought to mind; COVID-19. The period between 2017 and 2021 witnessed the COVID-19 pandemic which significantly impacted healthcare systems worldwide, and most patients were confined at homecare. The decline in *Staphylococcus aureus* and MRSA within the study period partly confirms the assertions that MRSA is endemic in healthcare settings (Abdelbary et al. 2020; Cookson 2011; Wong et al. 2022). Also, the decline may be attributed to other factors, including changes in patient behaviors, healthcare utilization patterns or increased awareness of hygiene practices during the pandemic. While our inference for the prevalence trend in our meta-analysis is debatable, the prevalence of MRSA by patient setting also supports our claim that no single MRSA was isolated from studies that reported recruiting outpatients. MRSA from DFU of inpatients was 2.2-fold that in mixed populations of inpatients and outpatients.

The regional prevalence distribution also presents an interesting outlook. Countries in the northern region of the continent pooled a greater chunk of *S. aureus* and MRSA isolates. Generally, North African countries are more developed than most countries in Sub-Saharan Africa. This development can be linked to better health infrastructure and better access to healthcare compared to other countries in SSA. Keeping in mind the assertion that MRSA is endemic in healthcare settings, the high prevalence of *Staphylococcus aureus* and MRSA in DFU in North Africa can be linked to the prevalence of diabetes, diabetic foot ulcers and subsequent hospitalization (Almeida et al. 2014) in the region.

Clinical samples used for microbiological investigations of DFU are very important. Our meta-analysis shows the uneven distributions of *Staphylococcus aureus* and *Pseudomonas aeruginosa* using different samples. However, tissue biopsy as supported in various literatures (Heravi et al. 2019; Travis et al. 2020) yielded higher number of isolates which may be culprits from the crime scene as deeper wounds according to Srivastava and Sivashanmugam (2020) are infected by pseudomonas species.

Our meta-analysis was limited in several ways. First, I^2 values for assessing heterogeneity were generally high, reflecting the likely influence of several determinants on the distribution of *Staphylococci* species in Africa (e.g., access to healthcare, climate and demographic factors). Secondly, this study may also be limited by lack of protocol registration. Registering reviews is not mandatory but is advised in order to achieve greater transparency, ensure better review standards, and avoid unnecessary duplication. This study was initiated to populate the literature review section of a student project; therefore, the authors decided it was inappropriate to register retrospectively. However, to the best of our knowledge there are no similar studies at the time of the review. Despite these limitations, these data provide an overview of the prevalence and antimicrobial resistance profiles of *Staphylococcus aureus* and *Pseudomonas aeruginosa* isolated from diabetic foot infections across Africa.

Conclusions

Staphylococcus aureus is the dominant DFU isolate in Africa and was largely resistant to penicillin G, Erythromycin, Cefoxitin, Tetracycline and Gentamicin, while *Pseudomonas aeruginosa* dominated gram-negative bacteria isolates and dominantly resistant to Ceftazidine, Amikacin, Gentamycin and Ciprofloxacin. Although Vancomycin and Imipenem are still effective against the duo, respectively, the observed prevalence of multidrug resistance among these isolates undermines antimicrobial therapy and patient outcomes. Also, there is a need to intensify screening for diabetic foot infection in Sub-Saharan Africa as majority of studies are populated in Northern Africa. The need for the development of an empirical antibiotic treatment protocol for infected DFU in Africa is invaluable. Finally, contrary to the assertion on gram-negative bacteria, particularly *Pseudomonas aeruginosa, Staphylococcus aureus* is the dominant bacterial isolate across Africa. However, the need for continuous surveillance of DFU for world health Organization priority pathogens including *Enterococcus faecium*, *Staphylococcus aureus*, *Klepsiella pneumoniae*, *Acinetobacter baumanii*, *Pseudomonas aeruginosa* and *Enterobacter specie* (ESKAPE) cannot be overemphasized.

Abbreviations

DFU	Diabetic foot ulcer
IDFU	Infected diabetic foot ulcer
DFI	Diabetic foot infections
MRSA	Methicillin-resistant *Staphylococcus aureus*

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42269-023-01119-5.

Additional file 1. Search query.

Additional file 2. List of Included Studies.

Additional file 3. JBI Critical Appraisal Checklist.

Additional file 4. Publication Bias Assessment Funnel Plots.

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DM conceived the idea, DM and MO searched and extracted data, DM and EE screened reports, while DM and EA appraised data and drafted the manuscript. EE and MO reviewed and edited the manuscript. All authors contributed equally and all authors have read and approved the manuscript.

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Declarations

Ethics approval and consent to participate
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Consent for publication
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Competing interests
All the authors declare that they have no competing interests whatsoever.

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