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Research Article

Adherence to biosafety and biosecurity protocols: An assessment of biomedical and veterinary laboratories in Benin

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ABSTRACT

Diagnostic laboratories play a crucial role in surveillance and epidemic preparedness. However, gaps in adherence to biosecurity and biosafety protocols in managing, isolating, storing, and disposing of infectious pathogens in these facilities pose a serious risk to the laboratory, local populations, and the surrounding environment. In this study, we evaluated adherence to biosecurity and biosafety protocols in 96 public and private biomedical and veterinary laboratories in Benin to identify and address such gaps. We followed a cross-sectional study design. We used the Biosafety and Biosecurity in Laboratory Tool to assess biomedical laboratories and the Laboratory Mapping Tool to assess veterinary laboratories. Data were collected using KoBoCollect and analyzed with R software version 4.0.5. Descriptive analysis, the chi-squared test, and logistic regression were used to analyze the data. The findings revealed that most laboratories did not comply with established guidelines. Of all laboratories surveyed, 42% presented a very high risk, 38% a high risk, 15% moderate risk, and 5% were low risk. Overall, 80% of biomedical laboratories and 100% of veterinary laboratories were rated high risk. To improve effective biosecurity practices in laboratories in Benin to an acceptable standard, it is essential to implement robust biosecurity and biosafety policies. Additionally, capacity-building sessions should be conducted for laboratory staff and managers to educate them on the latest biosecurity protocols.

1. Introduction

In recent years, the rise of highly contagious infectious diseases has adversely affected global health, leading to substantial mortality and morbidity that has hindered economic growth worldwide.[1] A prime example is the SARS-CoV-2 pandemic, which resulted in millions of deaths and illnesses across the globe.[2–4] From 2000 to 2021, a total of 309 laboratory-acquired infections (LAIs) were reported, with 94 cases involving 51 pathogens, resulting in eight fatalities (2.6 %). Additionally, 16 accidental pathogen escapes leading to LAIs were reported, involving dangerous agents like *Bacillus anthracis* and SARS-CoV.[5] These unprecedented biological threats have exposed vulnerabilities in health systems, economies, and international relations, emphasizing the urgent need to enhance biosecurity and biosafety measures, particularly in laboratory settings.[6,7]

Biosafety is defined as containment principles, technologies, and practices that are implemented to prevent unintentional exposure to biological material or their accidental release. Biosecurity is defined as the protection against, control of, and accountability for biological agents and toxins within facilities to prevent their loss, theft, misuse, diversion, unauthorized access, or intentional unauthorized release.[8] Globally, the implementation of biosafety and biosecurity varies greatly, particularly between developed and developing countries. Developed nations typically have strong regulatory frameworks, sufficient funding, and a culture of safety that leads to more effective practices. These countries have well-trained personnel and robust infrastructure, which minimize risks, safeguarding researchers and the community[9–11]. Conversely,

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developing countries face considerable challenges, including limited resources, inadequate training, and poor infrastructure, which impede effective biosafety measures.[12] Regions like Africa encounter unique difficulties, such as outdated facilities and insufficient training, exacerbating the risk of LAIs. Inconsistent regulations and a lack of funding further complicate efforts to standardize safety protocols. Cultural barriers and fragmented health systems also hinder coordinated responses to biological threats.[13]

Reports from the World Health Organization (WHO) and the Global Health Security Index reveal that most African countries have weak biosafety and biosecurity systems. For instance, in 2019, only 2 out of 42 countries scored above 50 % on the WHO Joint External Evaluation tool, with none exceeding 30 % in the Health Security Index.[14] In Benin, the 2021 Health Security index was just 25.4 %, with no Biosecurity and Biosafety score.[15] The WHO recommends integrating measurable biosafety and biosecurity criteria into national health strategies and conducting annual assessments to identify and address gaps.[14] Strategies include aligning local with international regulations, identifying national needs, and developing frameworks to strengthen biosafety and biosecurity practices.[12]

Implementing biosafety and biosecurity protocols is critical to preventing the release of pathogens from the laboratory, and adherence to these protocols in Benin remains unclear. In this study, we aimed to evaluate the level of compliance with biosecurity and biosafety measures and protocols in laboratories in Benin, identify weaknesses in their implementation, and provide sustainable and evidence-based recommendations to enhance practices and contribute to global health security.

2. Methods

2.1. Study framework and design

A total of 96 laboratories, including 93 biomedical laboratories and 3 veterinary laboratories, were assessed following a cross-sectional study design. Among the 93 biomedical laboratories, we identified 7 research facilities, 73 public facilities, and 13 private facilities, all operating at biosafety level 2 and below. The survey was conducted in November 2023. This study was a part of the BIOP-Benin project, funded by the U.S Department of State, Nonproliferation and Disarmament Fund and implemented by the Elizabeth R. Griffin Program. Approximately 20 interviewers were trained to evaluate biosafety and biosecurity practices and use data collection tools. The Ministry of Health, through the heads of the national laboratory, played a crucial role in training and deploying the interviewers and facilitating the participation of laboratory managers in the survey. The study received approval from the Ministry of Health via letter N 6410/MS/DC/DGMHED/DED/SA dated November 10, 2023.

2.2. Assessment tools

The Biosafety and Biosecurity in Laboratory Tool (BSSLAT)[16] developed by Integrated Quality Laboratory Services was used to assess the biomedical analysis laboratories. The BSSLAT tool is structured as a questionnaire with numbered modules, each addressing key biosafety and biosecurity themes: 1. Buildings and workflows; 2. Personnel management and training; 3. Good laboratory practice; 4. Cleaning, disinfection, sterilization, and waste management; 5. Emergencies; 6. Risk management; 7. Documentation and regulations; 8. Biosecurity; 9. Other risks, and 10. BSL-3 laboratories.

The Laboratory Mapping Tool (LMT)[17] developed by the Food and Agriculture Organization (FAO) was used for assessing veterinary laboratories. The FAO LMT generates a laboratory profile by scoring performance on critical aspects of laboratory management, infrastructure, and technical performance, ensuring appropriate sample handling, detecting, and reporting, and facilitating rapid responses to disease threats. The tool, formatted as a spreadsheet questionnaire in Microsoft Excel 2007, converts interviewer responses into an overall biosecurity and biosafety score. This score is accompanied by tabulated summaries and graphical representations of the laboratory's strengths and weaknesses in biosafety and biosecurity.

The LMT questionnaire covers four areas with 20 indicators, including: 1. Administrative management: general, staff health and safety, training and competence, operational procedures; 2. Good laboratory practice: containment, BSL3 containment, waste treatment, dispatch of infectious substances, animal facilities; 3. Engineering: building, chemical containment, chemical safety, emergencies, fire risk, electricity, microbiological safety station, biosafety manual/standard operating procedures (SOPs), personal protective equipment (PPE); 4. General situation: use and disposal of PPE.

We used these different tools (the BSSLAT for biomedical laboratories and the LMT for veterinary laboratories) because each is tailored to the specific requirements and operational environments of their respective fields. Whereas both tools are used to assess biosecurity and biosafety adherence, they differ in focus and scope to reflect the unique risks and workflows of biomedical versus veterinary laboratories. The BSSLAT focuses on compliance with health regulations related to human pathogens; the LMT highlights several distinct characteristics, including adherence to animal health regulations. Specific examples include requirements for biological quarantine in veterinary facilities, the use of specialized PPE for experimental animal settings, accreditation processes for both laboratories and animal facilities, qualifications for staff involved in animal care, and the oversight of animal ethics committees. These differences underscore the specific needs and regulatory frameworks pertinent to veterinary laboratories compared with biomedical ones. Each tool is specifically designed to meet the unique challenges and requirements of its respective field, with BSSLAT prioritizing human health and LMT concentrating on animal health and zoonotic diseases.

Both assessment tools (BSSLAT and LMT) are structured with modules comprising indicators, each featuring closed questions with possible yes, no, partial, and not-applicable answers. The tool generates a score for each indicator based on the answers to all related questions. The average score for each module is the mean of the scores for the indicators in that module. The overall score is the average of all module scores, summarizing overall capability. A laboratory achieves a satisfactory status when it meets key criteria, such as at least 50 % compliance with internationally recognized biosafety standards, which include proper handling, storage, and disposal of infectious materials, as well as physical containment measures. Additionally, the laboratory should have robust biosecurity controls in place, including restricted access to sensitive areas and materials, and only trained and qualified personnel should handle dangerous pathogens. Laboratory personnel should undergo continuous training on biosafety, biosecurity practices, and emergency response protocols. Furthermore, the laboratory should regularly conduct risk assessment to identify and address gaps, and a clear incident reporting and emergency response system should be maintained.

2.3. On-site assessment

The on-site assessment involved an introductory meeting with laboratory management, a thorough tour and inspection of the laboratory facilities following the sample processing workflow,

interviews with key personnel to complete the questionnaire, and a debriefing meeting with laboratory management. Responses were verified through inspections as well as additional documents and records, and photographs were taken for the report.

2.4. Statistical analysis

The data were collected using KoBoCollect, installed on each interviewer's smartphone, and were later exported to Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA) for recoding and then imported into R software version 4.0.5 for statistical analysis (The R Project for Statistical Computing, Vienna, Austria). Descriptive analysis was performed, followed by the chi-squared test to assess differences in variable distributions. Logistic regression (both univariate and multivariate) was used to determine associations between indicators and modules.

We focused on variables with significant effects on the indicators within each module to identify gaps. The p-values associated with the odds ratios (ORs) in the univariate regression indicated whether an OR differed significantly from 1, compared with the reference modality for each indicator. However, this did not determine whether a variable (i.e., indicator) significantly affected the model. Therefore, a top-down selection of explanatory variables was conducted, starting with the least significant variable, with monitoring changes in the Akaike information criterion (AIC). The final model included variables with p-values <0.05 and the minimum AIC. Significant variables were then included in the multivariate regression. ORs and chi-squared tests were considered significant at the $p < 0.05$ threshold. ArcGIS software was used for mapping.

3. Results

3.1. General characteristics of laboratories

Of the 93 biomedical analysis laboratories, 73 were in the public sector, 13 in the private sector, and 7 were research laboratories. Their locations are illustrated in Fig. 1. In terms of health coverage, 43 % of biomedical laboratories assessed covered an average population between 100,000 and 1,000,000, and 10 % (7/86) covered a population of over 1,000,000. The study findings showed that 52 % (45/89) of biomedical laboratories analyzed between 10,000 and 320,000 samples annually. Within this category, 22.2 % (10/45) had a satisfactory biosafety and biosecurity status. However, a substantial proportion of communal health center laboratories showed an unsatisfactory or critical level of biosafety and biosecurity.

3.2. Biomedical analysis laboratory scores on the various BSS LAT modules

3.2.1. General information

The assessment of biosafety and biosecurity practices revealed that biomedical analysis laboratories performed many activities, such as hematological and serological analysis, molecular biology, mycology, virology, food analysis, parasitology, and fertility analysis. We identified significant differences ($p < 0.05$) in performing hematological analysis, serologic testing (rapid tests only), virologic testing (culture); molecular biology tests (PCR/RT-PCR), water/food analysis; mycology testing, and fertility analysis.

Most biomedical laboratories (57 %) in this study did not own a copy of the ISO15189:2012 standards. Furthermore, most laboratory managers (59 %) had not received comprehensive training in quality management systems (ISO15189) and as many as 72 % had not received comprehensive safety training, including risk management. Only 14 % of laboratories had reported laboratory accidents in the previous 5 years.

3.2.2. Pathogens managed in investigated diagnostic laboratories

Table 1 displays the hazardous biological agents managed or stored in diagnostic laboratories in Benin. The most frequently detected agents comprise 22 pathogens categorized under risk groups of the US Centers for Disease Control and Prevention (CDC). These include *Plasmodium*, which was detected in 89 out of 93 laboratories (95.6 %). Hepatitis B and hepatitis C viruses (HBV and HCV, respectively) were detected in 86 and 81 laboratories, respectively; other agents included *Treponema pallidum* (72 laboratories), sensitive *Mycobacterium tuberculosis* (45 laboratories), *Salmonella* spp. (36 laboratories), *Escherichia coli* (32 laboratories), *Streptococcus* spp. (29 laboratories), *Vibrio cholerae* (28 laboratories), and *Shigella* spp. (23 laboratories). As for risk group 3 pathogens, the most commonly detected was HIV, detected in 84 laboratories, followed by resistant *Mycobacterium tuberculosis* (23 laboratories). Finally, risk group 4 pathogens included Ebola and Lassa viruses, detected in two laboratories.

Most facilities in which dangerous pathogens were detected had very low levels of biosafety and biosecurity, endangering laboratory workers as well as exposing the local population to the risk of hazardous pathogens potentially escaping from these centers. Indeed, in 60 %–90 % of laboratories with an unsatisfactory biosafety and biosecurity status, HBV and HCV, HIV, sensitive or resistant *M. tuberculosis*, *Salmonella* spp., *T. pallidum*, *V. cholerae*, *Neisseria meningitidis*, *E. coli*, as well as malaria and stool parasites were detected. Additionally, the two laboratories in which Lassa and Ebola viruses were detected did not meet satisfactory standards.

3.2.3. Gaps identified in biosafety and biosecurity in biomedical laboratories in Benin

Overall analysis of the investigation results for biomedical laboratories in Benin regarding their biosafety and biosecurity practices revealed acceptable scores (>50 %) recorded for two modules. These were the "Premises and workflow" module, with a score of 53.2 %, followed by the "Cleaning, disinfection, sterilization, and waste management" module, with a score of 65 % (Fig. 2). Apart from these two modules, the scores recorded for the remaining modules were below the recommended standard. Comparison of practices according to activity sectors (public, private, and research) of the biomedical analysis laboratories surveyed showed no significant differences at the 5 % threshold in the practices implemented.

3.2.3.1. Premises and workflow gaps. The identified gaps were related to buildings, biosafety assessment, as well as information, infection control, and risk groups. The available space in 36 % of laboratories was insufficient to ensure the quality and safety of patients and staff. Rooms for cleaning laboratory glassware and tools were separate from the laboratory testing rooms in fewer than half of the investigated laboratories. Technical rooms were logically organized and furnished to ensure a unidirectional workflow, thereby preventing the unnecessary movement of people, in only 40 % of laboratories. Approximately 70 % of laboratories had not undergone a building and safety assessment. Over half of the investigated laboratories had not developed an action plan to implement the recommended building improvements and safety assessments. Between 50 % and 85 % of laboratories did not have the ability to control laboratory temperature, humidity, airflow, pressure, or to address cracks and fissures. Additionally, half of laboratories lacked a written procedure describing the actions to take in case of a suspected laboratory-related infection or accident in which a staff member may have been infected. We found that laboratories with no workflow organization in place were 77 times

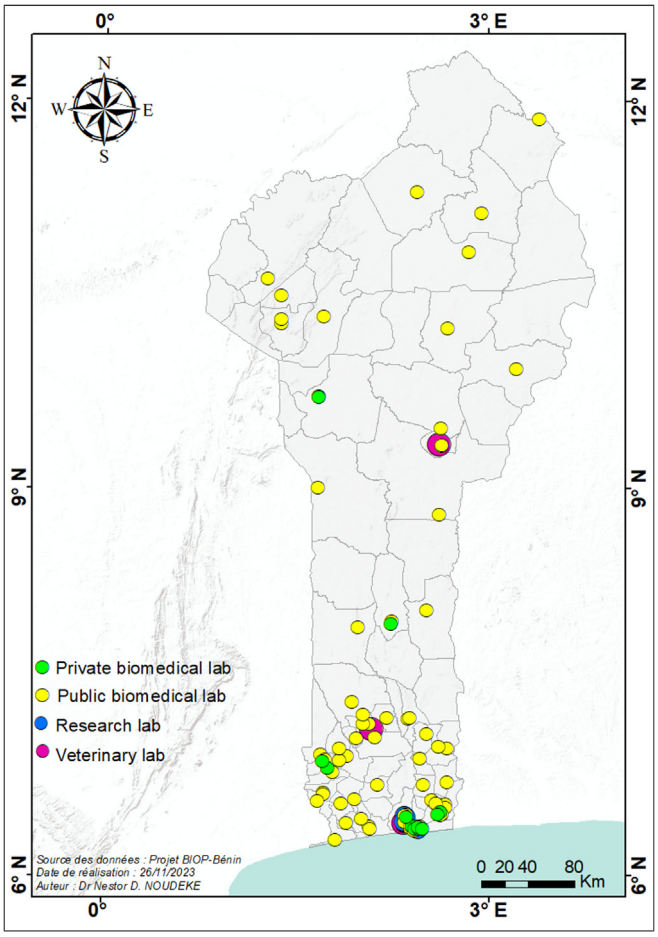


Fig. 1. Location of laboratories surveyed in Benin, 2023.

more likely to fail compliance with the premises and workflow assessment module (OR = 76.59, 95% CI: 8.48–2826.89, p = 0.002). It also emerged that those laboratories that had not set up a system for information about the prevention of infections and risk groups were 34 times (OR = 34.45, 5.25–823.47, p = 0.003) more likely to fail compliance with the assessment module on Premises and workflows (Table S1).

3.2.3.2. Staff management and training gaps. With the evaluation module on personnel management and training, we observed that more than half of biomedical analysis laboratories surveyed had not organized introductory training that includes biosafety and infection prevention for newly hired staff. Furthermore, the staff in nearly 45 % of the laboratories were not familiar with emergency procedures, including evacuation, fire management, and biological material spill response. Approximately 70 % of laboratories did not have a biosafety officer, and the few biosafety officers present were not retrained on a regular basis and often did not have a specific and comprehensive job description. More than half (62.37 %) of laboratories did not have a biosafety or related committee to discuss biosafety issues. More than half (62.37 %) of laboratories did not have a biosafety action plan. Moreover, laboratories that were not organized, with clearly designated and trained biosafety officers, were found to be 19 times more likely to fail compliance with the module on personnel management and training (OR = 18.53, 1.50–701.58, p = 0.047) (Table S2).

3.2.3.3. Good laboratory practices gaps. Indicator scores associated with the good laboratory practice assessment module in relation to the biomedical analysis laboratories showed that all 93 laboratories surveyed failed compliance. There were no clean/dirty areas clearly designated for blood sampling, sample preparation, or for biochemical, hematological, serological, bacteriological, and molecular analyses in 78 %–92 % of laboratories. Most laboratory staff never wore protective glasses. In some laboratories, personnel did not frequently wear PPE appropriate for dangerous pathogens. No laboratories had a sink dedicated solely to handwashing (i.e., one per unit in a large lab). In approximately 95 % of laboratories, the sinks were not sufficiently numerous or strategically located near exits. Most laboratories had not developed a procedure for handwashing. In all laboratories, personnel did not wash their hands every time they left the laboratory. Centrifuges and refrigerators were not disinfected at least once a month, with disinfection documented in a logbook in the laboratory. Equipment was not systematically disinfected before each maintenance step (external) in most laboratories, and cleaning and disinfection were not recorded in a logbook. Laboratories did not keep a list of all manipulations and equipment that could produce aerosols, 77 % did not have a biological safety cabinet (BSC), and 88 % did not have a protective screen for opening blood tubes. In total, 95 % of laboratories investigated did not transfer specimens to other laboratories when testing was not available, and 90 % did not have appropriate packaging for transferred samples. Finally, 79 % of laboratory managers were not trained in specimen transport according to international regulations (International Civil Aviation Organization/International Air Transport Association certification) (Table S3).

3.2.3.4. Cleaning, disinfecting, sterilization, and waste management gaps. Regarding indicators associated with the evaluation module on cleaning, disinfection, sterilization, and waste management, although the biomedical analysis laboratories surveyed were cleaned and disinfected regularly and properly by laboratory personnel, more than half did not perform annual or more frequent fumigation of microbiology laboratories. The competency of cleaning staff in terms of biosafety concepts was not assessed at least once a year. Laboratories whose staff had not mastered the concepts of cleaning and disinfection were 25 times more likely to fail the assessment module on cleaning, disinfection, sterilization, and waste management (Table S4).

3.2.3.5. Emergencies gaps. For the emergency assessment module, we observed that half of the laboratories investigated did not have fire extinguishers per unit or emergency power cutoff devices. Among all laboratories, 92 %–98 % lacked fire blankets and powerful portable lamps. Of laboratories that possessed this equipment, half needed to be rigorously inspected by an expert. In total, 85 %–89 % of laboratories did not have emergency equipment, such as safety showers and eye wash stations. Of all laboratories, 88 % had not conducted an emergency risk assessment (Table S5). In 66 % of laboratories, staff were not familiar with evacuation routes and procedures. Rehearsals had not been conducted for personnel involved in firefighting and fire prevention in most laboratories. In half of laboratories, staff were unaware of how to respond for different types of spills or accidents (e.g., from a BSC or centrifuge), and there were not enough complete spill kits in more than 70 % of laboratories. More than half of laboratories had staff who were not trained in the use of spill kits. In 79 % of laboratories, no simulations of emergencies under real conditions had been organized. Additionally, 71 % of cleaning staff had not been trained in the use of spill kits. As for the main gaps, there were no significant ORs.

3.2.3.6. Risk management gaps. Regarding this module, the gaps identified concerned risk assessment training, the analysis and implementation of corrective measures, verification, monitoring, and follow-up. In 70 % of the laboratories surveyed, staff were

Table 1
Biological safety status and hazardous biological agents handled or stored in diagnostic centers in Benin.

Biosafety and Biosecurity status of medical laboratories					
		Satisfactory	Unsatisfactory	total	P value
Pathogens	**Virus**				
	Hepatitis B virus (risk group 2)	14 (16.09 %)	73 (83.91 %)	87	p < 0.001
	Hepatitis C virus (risk group 2)	14 (17.28 %)	67 (82.72 %)	81	p < 0.001
	HIV (risk group 3)	13 (15.48 %)	71 (84.52 %)	84	p < 0.001
	Rubella virus (risk group 2)	10 (55.56 %)	8 (44.44 %)	18	P = 0.7
	Measles virus (risk group 2)	3 (75.00 %)	1 (25.00 %)	4	p = 0.47
	Rotavirus (risk group 2)	3 (75.00 %)	1 (25.00 %)	4	p = 0.4
	Dengue virus (risk group 2)	3 (50.00 %)	3 (50.00 %)	6	p = 1
	Lassa virus (risk group 4)	1 (50.00 %)	1 (50.00 %)	2	p = 1
	Ebola virus (risk group 4)	1 (50.00 %)	1 (50.00 %)	2	p = 1
	Bacteria				
	Sensitive *Mycobacterium tuberculosis* (risk group 2)	5 (11.11 %)	40 (88.89 %)	45	p < 0.001
	Resistant *Mycobacterium tuberculosis* (risk group 3)	4 (17.39 %)	19 (82.61 %)	23	p < 0.01
	Salmonella spp (risk group 2)	12 (33.33 %)	24 (66.67 %)	36	p < 0.001
	Treponema pallidum (risk group 2)	14 (19.44 %)	58 (80.56 %)	72	p < 0.001
	Vibrio cholerae (risk group 2)	10 (35.71 %)	18 (64.29 %)	28	p = 0.06
	Corynebacterium diphtheriae, C. ulcerans, C. pseudotuberculosis(Diphtheria) (risk group 2)	2 (50.00 %)	2 (50.00 %)	4	p = 1
	Neisseria meningitidis s (risk group 2)	8 (36.36 %)	14 (63.64 %)	22	p = 0.13
	Shigella spp (risk group 2)	10 (43.48 %)	13 (56.52 %)	23	p < 0.001
	E coli (risk group 2)	10 (31.25 %)	22 (68.75 %)	32	p < 0.001
	E coli O157: H7 (risk group 2)	6 (60.00 %)	4 (40.00 %)	10	p = 0.65
	Yersinia pestis (risk group 3)	7 (46.67 %)	8 (53.33 %)	15	p = 1
	Parasites				
	Malaria parasites (risk group 2)	15 (16.85 %)	74 (83.14 %)	89	p < 0.001
	Stool parasites (risk group 2)	14 (17.07 %)	68 (82.92 %)	82	p < 0.001

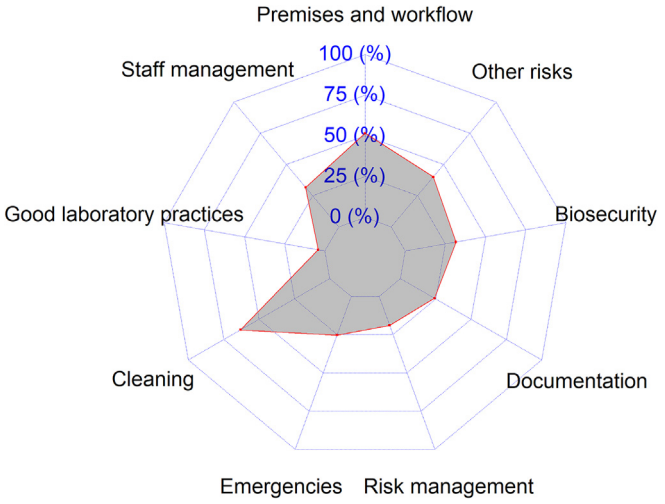


Fig. 2. Distribution of average scores by module during the assessment of biomedical laboratories in Benin, 2023.

not trained in risk assessment. In more than 60 % of the investigated laboratories, staff were unfamiliar with how to assess and quantify risks. No risk assessment exercises had been conducted in 84 % of the surveyed laboratories (Table S6). Additionally, more than 60 % of laboratories had not incorporated biosafety and risk assessment issues into their annual action plans. Regarding the main gaps, no significant ORs were identified.

3.2.3.7. Documentation and regulations gaps. We identified many gaps in the documentation and regulations evaluation module. In 79 % of biomedical analysis laboratories surveyed, there was no list of reference laboratories located abroad for the handling of pathogens with epidemic potential. Between 40 % and 60 % of laboratories did not have a copy of the national guidelines for laboratory waste treatment, biosafety, general laboratory safety, or good analysis practices available within the laboratory. Approximately 40 % of laboratories did not follow these guidelines. An up-to-date biosafety manual and material safety data sheets for all hazardous materials were missing in 76 % of laboratories. In three-quarters of laboratories, there was no SOP for cleaning the laboratory building, and staff were not familiar with the different classes of hazardous products and their numbers. Half of laboratories lacked an up-to-date sampling manual. Safety audit checklists, safety training and evacuation/fire drill forms, decontamination checklists and forms, and incident reporting and risk assessment forms were not easily or quickly accessible in more than 80 % of laboratories. No main gaps were identified, with no significant ORs (Table S7).

3.2.3.8. Biosecurity gaps. Table S8 shows indicators associated with the biosecurity evaluation module for the biomedical analysis laboratories surveyed. The gaps identified concerned the conditions of laboratory access and evacuation, signage and warnings, protection against theft, pathogen management, and computer protection and backups. In 76 % of laboratories, access to the facilities was controlled against unauthorized persons (visits, family, resellers); however, 84 % of laboratories did not maintain an up-to-date register of all external persons entering the laboratory and 59 % did not have biohazard signs. In 70 % of laboratories, some personnel did not wear appropriate PPE. Additionally, 65 % of doors to the laboratory and 45 % of windows were not reinforced for theft protection. In 94 % of laboratories, there was no alarm system present and functional. Regarding the management of pathogens, approximately three-quarters of laboratories did not register all hazardous materials in the laboratory, and 64 % had collections of pathogens strains that were stored without restricted access. In 38 % of laboratories, the stocks of pathogen strain collections were stored but not checked via regular inventory; 44 % of laboratories keep the stocks of positive sera (e.g., HIV, HBV, HCV) in a closed room without highly restricted access. In 65 % of laboratories, no logbook or computer database of all pathogens, sera, slides, and specimens was maintained; 46 % of laboratories did not have a specific policy regarding the use of USB sticks, and more than half of laboratory computer systems were not equipped with a firewall

to prevent unauthorized access to or theft of sensitive data. Laboratories without laboratory access and evacuation requirements were 70 times more likely to fail compliance (OR = 70.22, 4.60–5204.84, p = 0.014); laboratories without signs and warnings were 33 times more likely to fail compliance (OR = 33.28, 4.00–803.41, p = 0.005); laboratories without theft protection were 20 times more likely to fail compliance (OR = 20.28, 2.22–389.24, p = 0.017); laboratories without pathogen management were 19 times more likely to fail compliance (OR = 19.06, 1.76–598.77), p = 0.036), and laboratories without IT protection and backup were 506 times more likely to fail compliance (OR = 506.43, 17.75–104985.07, p = 0.004).

3.2.3.9. Other risks gaps. Table S9 shows indicators associated with the module assessing other risks. The gaps identified concerned electrical, physical, and radiological risks. Additionally, assessment revealed the following gaps. Laboratories without an electrical risk prevention system were 29 times more likely to fail compliance (OR = 28.54, 3.77–702.87, p = 0.007), and laboratories without a physical risk prevention system were 58 times more likely to fail compliance (OR = 58.42, 9.26–1181.47, p < 0.001).

3.2.4. Biological risk level and biosafety and biosecurity status of biomedical laboratories

Fig. 3 illustrates the levels of biological risk, defined as the probability of accidental or unintentional spread of dangerous microorganisms, as well as the biosafety and biosecurity status in the biomedical laboratories investigated. The evaluation scores were categorized as follows: a score $\leq$ 30 % indicated a very high risk, reflecting insufficient compliance and major gaps that require immediate corrective measures. A score between 31 % and 49 % signified a high risk, with some compliance efforts present but numerous weaknesses that necessitate urgent intervention. A score of 50 %–59 % reflected a moderate risk, indicating that some practices are implemented, but there are still shortcomings that need improvement. A score of 60 %–79 % indicated a low risk, showing overall compliance but with a few adjustments still required. Finally, a score of 80 % and above indicated a very low risk, signifying solid compliance with international standards, comprehensive measures in place, and adequate preparedness to respond to emergencies. [18] The results were concerning, with 42 % of the laboratories surveyed classified as presenting a very high risk and 38 % classified as high risk. This means that a staggering 80 % of the biomedical laboratories investigated fell into the categories of very high or high risk, which is deemed unacceptable. Only a small fraction (15 %) presented a moderate risk, and an even smaller proportion (5 %) were considered to be low risk. In addition to the biological risk assessment, the figure depicts the evaluation results for biosafety and biosecurity measures in these laboratories. The findings revealed that only 20 % of the biomedical laboratories had a satisfactory status in terms of biosafety and biosecurity, indicating that most laboratories surveyed were not adequately equipped or managed to prevent the spread of dangerous pathogens. This highlights a concerning gap in the implementation of essential safety protocols, posing a serious threat to both laboratory personnel and broader public health.

3.3. Veterinary laboratories

3.3.1. Strengths and gaps in biosafety and biosecurity practices

Figs. 4 and 5 show scores for the three veterinary laboratories surveyed using the indicators. These laboratories enforced policies prohibiting food storage, eating, drinking, smoking, applying makeup, or handling contact lenses in work areas. The access to these laboratories areas was restricted with signs indicating this restriction, and access to biosafety laboratories and freezer rooms was controlled and restricted to authorized staff, although door locks lacked access verification systems. The international biohazard symbol was displayed on the front door, but additional information was either absent or inaccurate. Our survey revealed gaps in several critical areas, including staff health and safety, the presence of a biosafety manual, good laboratory practices, containment measures, chemical risk management, emergencies, fire risk, electricity, and microbiological safety station. None of the laboratories surveyed met acceptable standards for biosafety and biosecurity, with high biological risks identified across the board. In the public veterinary laboratories, namely the Veterinary Diagnostic and Serosurveillance Laboratory of Parakou (LADISERO) and Veterinary Laboratory of Bohicon (LABOVET), some basic biosafety information and training were provided to staff but these measures fell short of ensuring a safe working environment. Although general biosafety training was documented and provided annually, the absence of more comprehensive safety protocols, such as maintaining inventories of hazardous materials and having secure storage facilities, highlights serious deficiencies in laboratory operations.

3.3.2. Inadequate emergency preparedness and waste management

Emergency preparedness in these laboratories was severely lacking. None of the surveyed laboratories had adequate emergency response plans or supplies, with only basic first aid kits available. This is particularly concerning given the high-risk nature of the work conducted in these facilities. Waste management practices were also insufficient, with issues regarding proper containment, decontamination, and disposal of laboratory waste. LADISERO demonstrated some adherence to waste management protocols, using incinerators and autoclaves; however, the overall approach remained inadequate, especially in laboratories like the Communicable Diseases Research Unit (URMAT) and LABOVET, where waste handling was poorly managed. Furthermore, there were no designated areas for specimen reception, and the laborato-

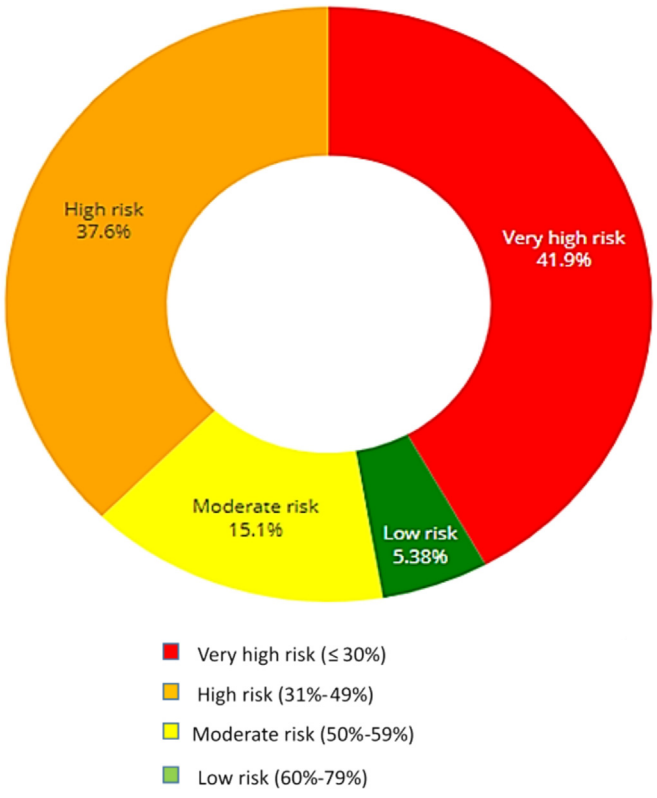


Fig. 3. Biological risk levels in biomedical laboratories.

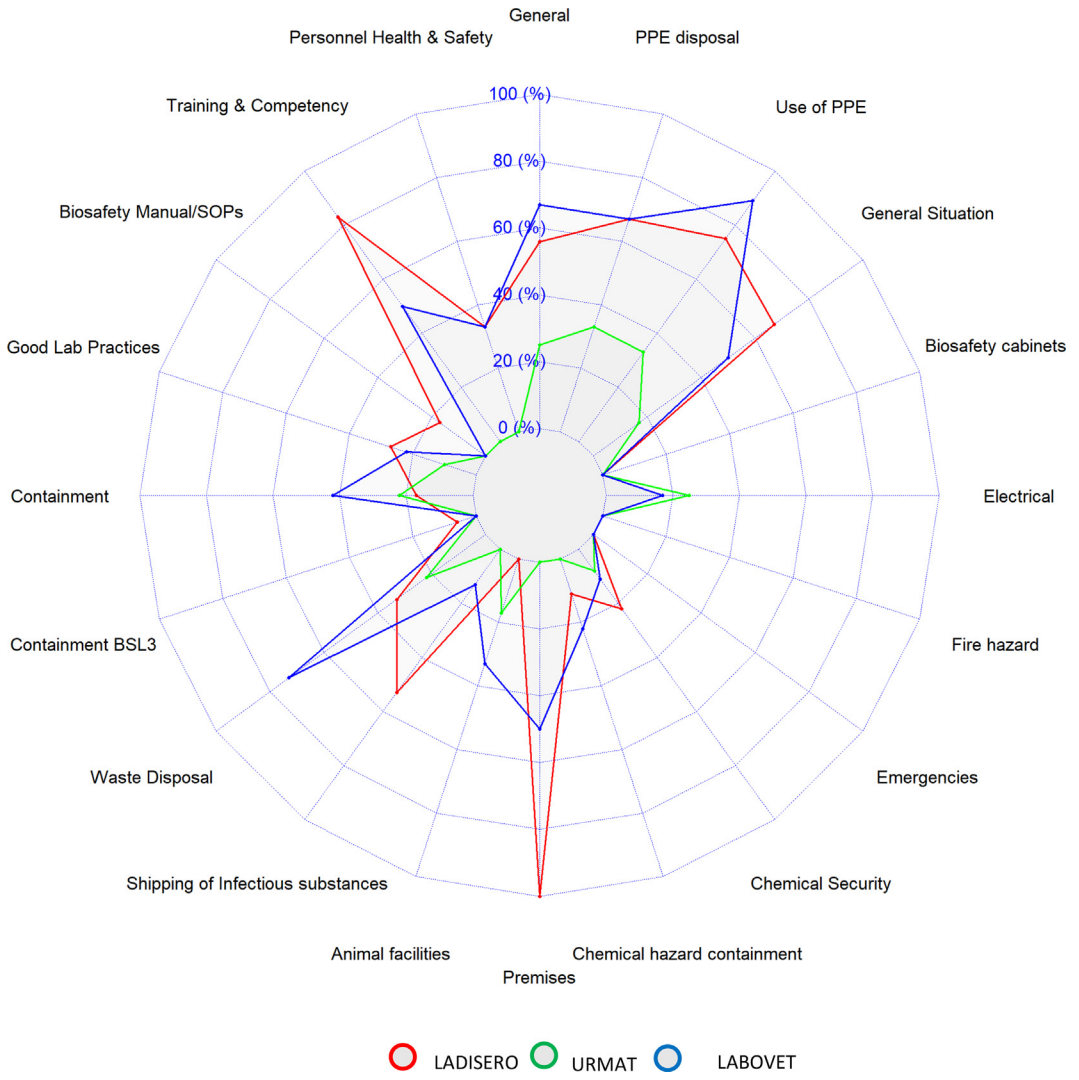


Fig. 4. Distribution of veterinary laboratory scores for evaluation indicators in Benin, 2023. LADISERO, Veterinary Diagnostic and Serosurveillance Laboratory of Parakou; LABOVET, Veterinary Laboratory of Bohicon; URMAT, Communicable Diseases Research Unit; PPE, personal protective equipment; BSL, biosafety level.

ries lacked proper systems for safe sample distribution and documentation.

3.3.3. Deficiencies in laboratory infrastructure and equipment

The laboratory infrastructure and equipment in these veterinary facilities were not up to the standards of both safety and functionality. BSCs, which are critical for containing pathogens, had not been tested by National Science Foundation-certified assessors for over 5 years. Emergency showers, necessary for chemical spill responses, were either unavailable or nonfunctional, and fire prevention measures were inadequate. Moreover, there was no integrated fire detection or automated fire suppression system in place, increasing the risk of catastrophic incidents. The lack of emergency eyewash stations and biological spill kits further underscored the urgent need for upgrading the infrastructure of these laboratories to meet international safety standards. These deficiencies highlight the pressing need for comprehensive improvements in veterinary laboratories' biosafety and biosecurity practices.

4. Discussion

In this study, we assessed the biosafety and biosecurity status of Benin's national laboratory system to propose interventions for addressing the identified shortcomings. For this purpose, we chose qualitative tools to calculate scores for the main biosafety and biosecurity indicators. This approach facilitated the identification of deficient areas, represented by indicators with the lowest scores, typically below 50 %.[19–22] Our findings align with those reported in Burkina Faso using the same assessment tools. [19] We reported higher scores in cleaning, disinfection, sterilization, and waste management (82 % vs. 42 %) and in good laboratory practices (40 % vs. 0 %). However, we found lower scores in biosecurity (25 % vs. 33 %) and documents/regulations (13 % vs. 18 %). Emergency management was slightly better in our study (20 % vs. 16 %), as was risk management (18 % vs. 5 %). Our results also showed that diagnostic laboratories handle or store various pathogens that could pose a serious risk to laboratory staff and the local population if accidentally released into the environment. Therefore, strict compliance with biosafety and biosecurity measures in diagnostic laboratories is crucial.[23]

Regarding biosafety and biosecurity practices in the investigated laboratories, our findings indicated that diagnostic facilities in Benin generally exhibit an unacceptable biosecurity status. Our results differed from those obtained by Muhammad et al. in Pakistan, which revealed an overall rate of compliance with biosecurity controls and measures of 80.67 % in research and diagnostic laboratories in Khyber Pakhtunkhwa Province, showing a positive

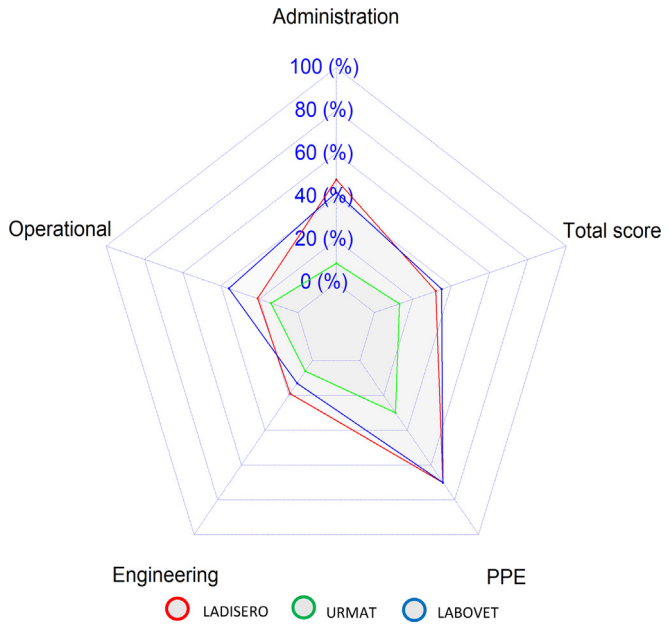


Fig. 5. Distribution of veterinary laboratory scores for modules and total scores in Benin, 2023. LADISERO, Veterinary Diagnostic and Serosurveillance Laboratory of Parakou; LABOVET, Veterinary Laboratory of Bohicon; URMAT, Communicable Diseases Research Unit.

situation in both research and diagnostic settings. [24] In biomedical diagnostic laboratories, we observed vulnerabilities in at least seven of the nine indicators comprising the BSSLAT tool. The most serious gaps identified were in good laboratory practice, risk management, documentation and regulation, biosecurity, personnel management, emergency preparedness, and the category of other risks. The lowest scores were noted for good laboratory practice indicators in biomedical diagnostic and research facilities. PPE was not consistently available to staff. The rate was similar to that during 2018 in Uganda, where Kagirita et al. reported a score of 35 % for the supply and use of PPE, which forms the basis of protection for laboratory personnel during work.[18]

In our study, handwashing was not systematic, and the management of dangerous pathogens, sharps, and aerosols by staff was substandard. This critical situation is alarming because good laboratory practices are essential for containing biological hazards in the laboratory and reducing the risk of staff contamination.[25–26] Most biomedical laboratories did not comply with visitor access restrictions, likely owing to a lack of biosecurity managers and resources allocated to laboratory management. Another major shortcoming identified was non-compliance with risk and emergency management protocols.

Many managers had not received training in risk assessment, and emergency kits and equipment were often unavailable during assessments. Effective risk assessment using a laboratory management system is crucial for preventing undesirable events.[27–28] Non-compliance with several other indicators, such as biosafety, workflow organization, building standards, and personnel management, may facilitate the spread of pathogenic microorganisms in biomedical laboratories. This underscores the weaknesses in Benin's national laboratory system in terms of biorisk management. This is a recurring issue in many African countries according to Maruta et al., who reported that both WHO Joint External Evaluations and 2021 Global Health Security Index reports indicated weakened biosafety and biosecurity systems among the Africa Union Member states, with only Kenya and South Africa scoring 50 % in Biosafety.[14] A study conducted among biomedical diagnostic laboratories in Nigeria revealed a very low biosafety compliance rate among evaluated biomedical laboratories, particularly regarding infrastructure design, availability of PPE, equipment, and biosecurity.[29] Strengthening the capacity of the national laboratory system in biosafety and biosecurity is therefore a priority for the optimal management of biological risks in the sector.

In our study, the observations made in the veterinary laboratories that were investigated highlighted the very low biosafety compliance rate among laboratories and lack of special legislation to regulate biosafety practices in the sector. Also in Benin, Sodjinou et al. reported similar results when investigating biosecurity and biosafety practices in LADISERO in 2021.[30] Indeed, those authors found that the overall score for laboratory biosafety and biosecurity was 42.4 %, versus 35.4 % in our study. That study revealed the categories that performed best, with scores exceeding 60 %; these were containment, waste disposal, and PPE disposal. Furthermore, most laboratories lacked a biosafety and accident prevention program.

Overall, these gaps in terms of biosafety and biosecurity in many laboratories in Benin can be explained by several factors, including the lack of necessary infrastructure to comply with international biosafety standards, such as insufficient containment facilities, outdated equipment, and inadequate waste disposal system, which increase the risk of exposure to hazardous biological materials; a serious lack of training programs for laboratory personnel on biosafety and biosecurity practices; and the absence of robust national policies and strict regulatory frameworks to govern these practices. Many laboratories do not conduct regular risk assessment to identify potential hazards or implement necessary safety measures, leaving them ill-prepared to handle emergencies or contain accidental spills and exposures. The lack of consistent monitoring and evaluation mechanisms further hampers the ability to assess compliance with biosafety and biosecurity standards, making it difficult to identify areas needing improvement. Resource constraints, including limited funding and resources, hinder the development of effective biosafety and biosecurity programs, with laboratories struggling to acquire essential materials, maintain equipment, and implement training programs, which affects their operational effectiveness. Lastly, there is minimal awareness about biosafety and biosecurity issues among the general public and stakeholders, which can lead to insufficient political will and investment in necessary safety infrastructure and training initiatives.

Several actions are recommended to address the gaps in biosafety and biosecurity practices in Benin's biomedical and veterinary laboratories. First, regular and thorough training programs should be implemented for laboratory staff, covering initial orientation for new employees and continuing education to ensure adherence to best practices, as implemented in Burkina Faso and Kenya. Additionally, establishing a "Training of Trainers" program is crucial to develop a network of skilled trainers within the country, ensuring the sustainability of training efforts.[31] It is also essential to formulate and enforce detailed biosafety and biosecurity guidelines and regulations tailored to Benin's needs. This should include developing and implementing SOPs for laboratory processes, such as waste management, emergency response, and equipment maintenance as well as good laboratory practices.

The government of Benin, along with its financial partners, should allocate sufficient resources to support the above initiatives. This includes funding for training programs, equipment procurement, infrastructure improvement, and research into local biosafety and biosecurity challenges. Increasing the recruitment of personnel skilled in biosafety and appointing dedicated biosafety and biosecurity officers are also vital steps. Moreover, establishing a supportive supervision system will help ensure that laboratories consistently adhere to biosafety and biosecurity stan-

dards. Facilitating knowledge exchange and learning from countries with advanced biosafety and biosecurity practices, such as the United States, can provide valuable insights and practical solutions.

5. Conclusion

In the present study, via collaboration among researchers from the University of Abomey-Calavi, the Ministry of Health, the Pasteur Institute of Morocco, and the Elizabeth R. Griffin Program in the United States, we assessed biosafety and biosecurity practices in biomedical and veterinary laboratories in Benin. Our findings revealed that most laboratories investigated do not have a satisfactory status in terms of biosafety and biosecurity. Substandard laboratories present a proven biological risk that could be the source of infections and emerging diseases that adversely affect laboratory staff and the general population. Enhanced infrastructure, robust training programs, strengthened regulations, increased funding, and improved global partnerships are essential to overcoming these challenges and safeguarding public health in Benin. This study calls for joint action by health stakeholders, particularly government authorities and researchers, to urgently implement biosafety and biosecurity policies and practices to help improve public health in the country.

CRediT authorship contribution statement

Philippe Sessou: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Nestor Noudeke:** Methodology, Formal analysis, Data curation. **Yves Eric Denon:** Methodology, Investigation. **Aretas Tonouhewa:** Methodology, Formal analysis, Data curation. **Alban Zohoun:** Methodology, Investigation. **Nassirou Boukary:** Methodology, Investigation. **Désirée Metodakou:** Methodology, Investigation. **Brian Samuelson:** Writing – review & editing, Validation. **Dana Hag Hamed:** Writing – review & editing, Validation, Methodology. **Jenny Zhao:** Writing – review & editing, Validation. **Sumegha Asthana:** Writing – review & editing, Validation. **Mohammed Abid:** Writing – review & editing, Validation. **Erin M. Sorrell:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jobb.2024.11.001.

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