Rawafed Almarefa Journal مجلة روافد المعرفة
ISSN: 2709-0345 Volume: 7, Issue: 13, (2026), Pages: 26-49

Assessment of Biosafety and Biosecurity Practices at Diagnostic Medical Laboratories in Tarhuna, Libya: A cross-sectional study

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تقييم ممارسات السلامة والأمن الحيوي في المختبرات الطبية التشخيصية بمدينة ترهونة، ليبيا: دراسة مقطعية

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Received: 20-8-2026; Accepted: 27-08-2026; Published: 17-09-2026

Abstract

Background: Diagnostic medical laboratories routinely handle potentially infectious specimens, making adherence to biosafety and biosecurity standards essential for protecting laboratory personnel, patients, and the wider community. National assessments indicate that Libya still lacks an approved regulatory framework for laboratory bio-risk management, and empirical data on everyday practice at the local level remain scarce, particularly outside the main urban centers. **Aim:** To assess the level of compliance with biosafety and biosecurity standards among public and private diagnostic medical laboratories in Tarhuna, Libya, and to identify the principal barriers to implementation. **Methods:** A cross-sectional study was conducted between December 2025 and February 2026 in 20 diagnostic medical laboratories (five public and 15 private) in Tarhuna, Libya. Data were collected from 48 laboratory staff members using a structured self-administered questionnaire complemented by a direct observational assessment checklist covering infrastructure, personal protective equipment (PPE), biological waste management, training, and general safety/emergency preparedness. Descriptive statistics (frequencies and percentages) were computed, and the findings are presented in tables and figures in the following sections. **Results:** Most surveyed laboratories were privately operated (75.0%). Three-quarters of the staff (75.0%) reported having received biosafety or biosecurity training. Glove use was universal (100.0%), whereas none of the respondents used protective goggles (0.0%). Direct observation revealed a mean compliance ranging from

40.0% for general safety and emergency preparedness to 75.0% for biological waste management. The most frequently reported barriers to implementation were a lack of equipment (34.7%) and training (30.6%). **Conclusion:** Biosafety and biosecurity practices among diagnostic laboratories in Tarhuna showed partial compliance with recommended standards, with pronounced deficits in protective eyewear, emergency preparedness, and proper documentation. Strengthening equipment provision, structured training, and national regulatory oversight are recommended to reduce the risk of laboratory-acquired infections and biosecurity deficiencies.

Keywords: *biosafety, biosecurity, diagnostic laboratories, personal protective equipment, Libya, Tarhuna.*

الملخص

الخلفية : تتعامل المختبرات الطبية التشخيصية بشكل روتيني مع عينات قد تكون معدية، مما يجعل الالتزام بمعايير السلامة والأمن الحيوي أمرًا ضروريًا لحماية العاملين في المختبرات والمرضى والمجتمع ككل. وتشير التقييمات المحلية إلى أن ليبيا لا تزال تفتقر إلى إطار تنظيمي معتمد لإدارة المخاطر البيولوجية في المختبرات، كما لا تزال البيانات الميدانية حول الممارسات اليومية على المستوى المحلي محدودة، ولا سيما خارج المدن الرئيسية. **الهدف :** تقييم مستوى الالتزام بمعايير السلامة والأمن الحيوي في المختبرات الطبية التشخيصية العامة والخاصة في ترهونة، ليبيا، وتحديد العوائق الرئيسية أمام تطبيق هذه المعايير. **المنهجية :** أُجريت دراسة مقطعية خلال الفترة من ديسمبر 2025 إلى فبراير 2026، شملت 20 مختبرًا طبيًا تشخيصيًا في ترهونة (5 مختبرات عامة و15 مختبرًا خاصًا). جُمعت البيانات من 48 من العاملين في المختبرات باستخدام استبيان منظم ذاتي التعبئة، إلى جانب نموذج للتقييم بالملاحظة المباشرة شمل البنية التحتية، ومعدات الوقاية الشخصية(PPE) ، وإدارة النفايات البيولوجية، والتدريب، والسلامة العامة والاستعداد لحالات الطوارئ. وحُسبت الإحصاءات الوصفية، بما في ذلك التكرارات والنسب المئوية، وعُرضت النتائج في جداول وأشكال بيانية. **النتائج :** كانت غالبية المختبرات المشمولة في الدراسة تابعة للقطاع الخاص (75.0%). وأفاد ثلاثة أرباع العاملين (75.0%) بالمختبرات المستهدفة بتلقيهم تدريبًا في مجال السلامة والأمن الحيوي. وكان استخدام القفازات شاملًا (100.0%)، في حين لم يُبلغ أي من المشاركين عن استخدام النظارات الواقية (0.0%). وأظهر التقييم بالملاحظة المباشرة أن متوسط مستوى الالتزام تراوح بين (40.0%) في مجال السلامة العامة والاستعداد لحالات الطوارئ و75.0% في مجال إدارة النفايات البيولوجية. وكانت أكثر العوائق التي أبلغ عنها المشاركون شيوعًا أمام التطبيق هي نقص المعدات (34.7%) ونقص التدريب (30.6%) **الخلاصة :** تُظهر ممارسات السلامة والأمن الحيوي في المختبرات التشخيصية في ترهونة التزامًا جزئيًا بالمعايير الموصي بها، مع وجود أوجه قصور واضحة في حماية العين، والاستعداد لحالات الطوارئ، والتوثيق. ويوصى بتعزيز توفير المعدات، وتطبيق برامج تدريبية منظمة، ودعم الرقابة التنظيمية للحد من مخاطر العدوى المكتسبة داخل المختبرات والحد من أوجه القصور في الأمن الحيوي.

الكلمات المفتاحية: : *السلامة الحيوية؛ الأمن الحيوي؛ المختبرات التشخيصية؛ معدات الوقاية الشخصية؛ ليبيا؛ ترهونة.*

1. Introduction

Laboratory biosafety refers to the principles, technologies, and practices implemented to prevent unintentional exposure to biological agents and toxins, whereas laboratory biosecurity refers to the institutional and personal security measures that prevent the loss, theft, misuse, diversion, or intentional release of such agents (World Health Organization [WHO], 2020).Together, these two complementary domains form the basis of biorisk management, which the World Health Organization (WHO) and the United States Centers for Disease Control and Prevention (CDC) consider a core requirement for any facility that collects, handles, or stores clinical specimens and pathogenic microorganisms (Centers for Disease Control and Prevention [CDC] & National Institutes of Health [NIH], 2020; WHO, 2020). Diagnostic medical laboratories are of particular concern because staff members routinely handle blood, body fluids, and other potentially infectious material, often without knowing in advance which specimens carry a transmissible pathogen (CDC & NIH, 2020).

Laboratory-acquired infections and biosafety lapses continue to be documented worldwide, and the fourth edition of the WHO Laboratory Biosafety Manual has shifted the global standard from a rigid, biosafety-level-based model to a risk- and evidence-based approach that requires each facility to conduct its own risk assessment and tailor engineering controls, personal protective equipment (PPE), training, and standard operating procedures accordingly (WHO, 2020). The companion WHO Laboratory Biosecurity Guidance, updated in 2024, further emphasizes institutional governance, an Institutional Biosafety Committee structure, inventory control, and, increasingly, cyber-biosecurity of laboratory information systems (WHO, 2024).

In Libya, the Joint External Evaluation of International Health Regulations core capacities, conducted in 2018, found that although biorisk management training activities had been introduced with support from the WHO, the World Organization for Animal Health, Georgetown University, and Sandia National Laboratories, the country had not yet adopted binding national legislation on laboratory biosafety and biosecurity, and no single agency had been designated to enforce such standards (WHO, 2019). Consistent with this finding, the 2021 Global Health Security Index reported no verifiable evidence of national biosecurity regulations governing physical containment, failure reporting, or personnel reliability programs in Libyan laboratories (Nuclear Threat Initiative [NTI] et al., 2021). Since then, the Libyan National Committee for Biosafety and Bioethics has approved a national biological-ethics regulatory document that sets out standards and requirements for biosafety and bioethics review of scientific research, which now forms the reference framework used by institutional ethics subcommittees across Libyan universities (Libyan National Committee for Biosafety and Bioethics, 2022). More recently, a 2026 WHO Regional Office for the Eastern Mediterranean mission to strengthen Libya's public health laboratory network identified biosafety and biosecurity, together with workforce capacity and quality management, as priority areas requiring reinforcement (WHO Regional Office for the Eastern Mediterranean, 2026). Taken together, these reports point to a regulatory framework that has advanced on paper since 2018, but whose translation into consistent day-to-day practice at individual facilities remains incomplete, as this study will show.

At the facility level, evidence remains limited but is growing. An assessment of diagnostic clinical laboratories in Tripoli found low compliance across nearly every biosafety and biosecurity domain examined, including personal protective equipment use, waste segregation, biohazard signage, written standard operating procedures, and biosafety training (Ben Ashur et al., 2017). A separate study of graduated laboratory technicians working in biological, medical, and food-testing institutions in Misurata similarly found that biorisk management content was largely absent from university curricula and that biosecurity measures such as restricted access, sample-transport procedures, and proper waste disposal were implemented by only a minority of institutions (Rhouma et al., 2021). However, both studies focused on Libya's two largest coastal cities. Diagnostic laboratories in Tarhuna, a city with a growing population and a mixed public-private laboratory sector, have not previously been evaluated, and no prior Libyan study has combined self-reported staff data with an independent, structured field checklist, as done here. Given the well-documented association between inadequate biosafety infrastructure, insufficient training, and increased occupational and public health risks in comparable low-resource settings (Ahmed et al., 2022; Alam et al., 2022; Bajjou et al., 2019; Elduma, 2012; El-Shokry et al., 2022; Halatoko et al., 2024; Kabamba-Tshikongo et al., 2026; Nik Mohd Razali et al., 2025; Padde et al., 2022; Shakoor et al., 2016; Sodjinou et al., 2021; Tadesse et al., 2025), a locally grounded assessment is needed to guide targeted interventions in Tarhuna.

This study aimed to assess the level of compliance with biosafety and biosecurity standards among public and private diagnostic medical laboratories in Tarhuna, Libya, by combining self-reported staff data with direct onsite observation. The specific objectives were as follows: (1) to describe the sociodemographic and professional characteristics of laboratory staff; (2) to quantify self-reported practices related to PPE use, biological waste disposal, and training; (3) to objectively verify infrastructure, PPE availability, waste management, training documentation, and emergency preparedness through a structured field checklist; and (4) to identify the principal barriers to the implementation of biosafety and biosecurity practices as perceived by laboratory personnel.

2. Methods

2.1 Study Design

We conducted a descriptive cross-sectional assessment of compliance with biosafety and biosecurity standards among medical diagnostic laboratories in Tarhuna, Libya. Both public and private laboratories were included, and we combined a self-administered staff questionnaire with a structured, observer-completed field checklist to determine whether self-reported practice aligned with what was observed on site.

2.2 Study Setting and Period

This study was conducted in Tarhuna, Libya, between December 2025 and February 2026. This period covered laboratory identification, field visits, data collection, and subsequent analysis of findings.

2.3 Study Population, Sampling, and Eligibility Criteria

The target population comprised diagnostic medical laboratories operating in Tarhuna and their staff. At the time of the study, no comprehensive, up-to-date register or sampling frame existed that listed all diagnostic laboratories operating in the city, public or private; therefore, the total number of eligible laboratories in Tarhuna could not be established with confidence, and a formal probability sample could not be drawn from the full population. To manage this constraint, laboratories operating in Tarhuna were first identified through professional referrals and field enumeration; from the pool of laboratories that could be reached and that agreed in principle to take part, 20 laboratories (five public, 15 private) were then selected at random for inclusion. Because the size of the full underlying population of laboratories in the city remains unknown, we do not report the 20 included laboratories as a percentage of all laboratories operating in Tarhuna, and we do not treat the sample as a formal probability sample of that population.

The laboratory eligibility criteria were as follows: (a) operating as a diagnostic medical laboratory (public or private) within the Tarhuna city limits during the study period and (b) laboratory management agreeing to a site visit and assessment. Laboratories were excluded if they could not be reached within the study period or if the management declined to participate.

Staff selection followed a different logic from laboratory selection and was reported separately to avoid conflating the two. Within each participating laboratory, the staff eligibility criteria were as follows: (a) working in a laboratory or laboratory-support role (technician or administrative staff directly involved in laboratory operations) and (b) present in the laboratory on the day of the visit and willing to complete the questionnaire. No attempt was made to randomly sample staff within laboratories; rather, all eligible staff present and willing to participate on the day of the visit were invited. This was an availability- or convenience-based sampling approach rather than a random sampling approach. This distinction is important because staff members who are on duty or are willing to complete a questionnaire administered by visiting researchers may not be representative of all staff members in a given laboratory. For example, more senior or safety-conscious staff members may be more likely to be present or agree to participate, which raises the possibility of selection bias in the staff-level (though not necessarily the laboratory-level) findings. We return to this point in Section 6. In total, 48 staff members from the 20 laboratories met the criteria and completed the questionnaire.

2.4 Data Collection Tools and Operational Definitions

Data were collected using two complementary instruments: a structured questionnaire administered to the laboratory staff and a direct observational assessment checklist completed by the research team during the same visit. Both instruments were developed by the research team specifically for this study, drawing on the biosafety and biosecurity domains and indicators described in the WHO Laboratory Biosafety Manual (WHO, 2020) and the CDC/NIH Biosafety in Microbiological and Biomedical Laboratories guidance (CDC & NIH, 2020), and informed by the item content of the two most closely comparable Libyan facility assessments conducted in Tripoli (Ben Ashur et al., 2017) and Misurata (Rhouma et al., 2021). The questionnaire was administered in Arabic, and the research team completed the field checklist in Arabic.

The questionnaire addressed the use of personal protective equipment (PPE), methods of biological waste disposal, staff perceptions of the adequacy of biosafety infrastructure, receipt of biosafety and biosecurity training, and perceived barriers to implementation. The observational checklist independently verified the availability and implementation of 19 items across five domains: infrastructure, PPE, biological waste management, training, and general safety and emergency preparedness. Each checklist item was scored by the research team as present ("Yes") or absent ("No") based on what was directly observed at the time of the visit. The availability and correct use of PPE were recorded as separate items. Laboratory records were not reviewed unless they were physically shown to the research team during the site visit. The operational definitions used for each checklist domain are listed in Table 1.

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Before fieldwork, the questionnaire and checklist were reviewed internally by the research team for face and content coverage issues. No formal pilot study or reliability testing was conducted before the main data collection.

Table 1. Operational Definitions Used for the Field Assessment Checklist

Domain	Operational definition of "Yes"
Infrastructure	Adequate ventilation, designated hazardous sample areas, warning signage, and emergency exits were physically present and visible during the visit.
Personal protective equipment	Gloves, coats, and masks were available in sufficient quantities. Proper PPE use was recorded separately when on-duty staff members were directly observed wearing gloves and masks..
Biological waste management	Waste segregation, dedicated containers, and disposal according to the approved protocols were visibly implemented. Waste management records were accepted only when physical or logbook records were shown..
Biosafety training	Regular and specific biosafety training was recorded as "Yes" only when supporting documentation, such as certificates or attendance records, was available.
General safety and emergency preparedness	Fire extinguishers and emergency equipment were physically present and apparently functional where checkable. Written emergency plans and incident-reporting procedures were required for a " yes " rating.

2.5 Statistical Analysis

The data were coded, entered, and analyzed using SPSS. Descriptive statistics, including frequencies and percentages, were used to summarize all questionnaire and checklist item data. The findings are presented in tables and graphical form. Inferential comparisons, such as chi-square or Fisher's exact tests, between public and private laboratories were not performed because the available dataset consisted of aggregate item counts rather than laboratory- or staff-level linked records. Valid inferential testing requires linked information on grouping variables and corresponding outcomes for each laboratory or staff member, which was not available in the current dataset. Therefore, statistical tests were not constructed from aggregated marginal totals, as they would not provide statistically valid results.

2.6 Ethical Considerations

Participation in the staff questionnaire was voluntary, and verbal informed consent was obtained from each participant before administration. No personal identifying information was collected, and all data were anonymized prior to analysis.

3. Results

A total of 20 diagnostic medical laboratories and 48 laboratory staff members were included in this assessment. The results are presented in three parts: (3.1) characteristics of the surveyed laboratories and staff, (3.2) staff-reported biosafety and biosecurity practices, and (3.3) findings of the direct field assessment.

3.1 Characteristics of Laboratories and Staff

Fifteen of the 20 laboratories (75.0%) were privately run and five (25.0%) were public (Table 2), a split that leans even more toward the private sector than the one reported from Tripoli, where 25 of 35 sampled laboratories (71.4%) were private (Ben Ashur et al., 2017).

Table 2. Distribution of Diagnostic Medical Laboratories by Sector (N = 20)

Laboratory sector	n	%
Public laboratories	5	25.0
Private laboratories	15	75.0

Laboratory sector	n	%
Total	20	100.0

Among the 48 staff who participated, a little over half held a bachelor's degree (52.1%), and the rest held a higher diploma (47.9%); nobody in the sample held a master's degree or relied on short courses alone in place of a formal qualification (Table 3). Almost everyone was a working technician (97.9%) rather than administrative staff (Table 4), and the workforce skewed young: 43.75% had five years of experience or less, another 41.67% had five to ten years, and only 14.58% had been in the field longer than a decade (Table 5)

Table 3. Educational Qualification of Laboratory Staff (N = 48)

Qualification	n	%
Bachelor's degree	25	52.1
Higher diploma	23	47.9
Master's degree	0	0.0
Training courses only	0	0.0
Total	48	100.0

Table 4. Professional Role of Laboratory Staff (N = 48)

Professional role	n	%
Laboratory technician	47	97.9
Administrative staff	1	2.1
Total	48	100.0

Table 5. Years of Professional Experience (N = 48)

Years of experience	n	%
1-5 years	21	43.75

Years of experience	n	%
5-10 years	20	41.67
10-15 years	4	8.33
>15 years	3	6.25
Total	48	100.0

3.2 Staff-Reported Biosafety and Biosecurity Practices

Asked directly, 75.0% of employees said they had received biosafety or biosecurity training, leaving one in four (25.0%) who had not (Table 6). In contrast to the other two Libyan facility studies, this represents a real difference: in Tripoli, 88.3% of technicians had received no formal biosafety training (Ben Ashur et al., 2017), and in Misurata, only 8.9% of graduated technicians reported being trained by their employer, with only 12% remembering biorisk management as a course in its own right at university (Rhouma et al., 2021). The comparisons are not perfect, as question wording differed across the three studies, but the gap is large enough that training coverage in Tarhuna's diagnostic sector appears to be noticeably better than in these two larger cities, even if a quarter of staff here remain untrained. As noted in Section 2.3, staff were not randomly sampled within laboratories; therefore, this figure describes the staff who happened to be present and willing to participate, not necessarily the full workforce.

Table 6. Training in Biosafety and Biosecurity (Staff-Reported, N = 48)

Response	n	%
Yes	36	75.0
No	12	25.0
Total	48	100.0

Turning to protective equipment, gloves were used by every respondent (100.0%), masks by 85.4%, and laboratory coats by 70.8%, but none reported wearing protective goggles (Table 7). Eye protection, in other words, was the clear outlier. Tripoli's technicians reported glove-and-coat use, measured as a single combined indicator, at 64.8%, with 8.2%

saying they never used either item (Ben Ashur et al., 2017); taken at face value, glove use in Tarhuna runs somewhat ahead of that.

Table 7. Personal Protective Equipment Used by Laboratory Staff (N = 48)

PPE type	n	%
Gloves	48	100.0
Laboratory coats	34	70.8
Protective goggles	0	0.0
Masks	41	85.4
Other	0	0.0

Regarding waste disposal, seven out of ten staff (70.8%) said that biological waste went into dedicated containers, and a quarter (25.0%) reported that it was at least separated from general waste; nobody described their laboratory as having no procedure at all (Table 8). This is a rather different picture from Misurata, where only 10.9% of respondents thought that waste was handled according to required procedures (Rhouma et al., 2021), or from Tripoli, where 77.6% of laboratories had no proper waste segregation and 82.1% lacked any procedure for liquid biological waste (Ben Ashur et al., 2017).

Staff confidence in their own infrastructure was high across the board: 85.4% believed their laboratory had adequate biosafety infrastructure, 14.6% were unsure, and no one said outright that it was inadequate (Table 9), a perception worth holding up against what the field checklist actually found, which we do in Section 3.3 and return to at greater length in the Discussion.

Table 8. Methods of Biological Waste Disposal Reported by Staff (N = 48)

Waste-disposal method	n	%
Separation of biological waste from general waste	12	25.0
Disposal in dedicated containers	34	70.8
No specific procedures	0	0.0

Table 9. Staff Perception of Biosafety Infrastructure Adequacy (N = 48)

Response	n	%
Yes	41	85.4
No	0	0.0
Not sure	7	14.6
Total	48	100.0

When asked about barriers to implementing biosafety practices, staff most frequently cited a lack of equipment (34.7% of responses) and a lack of training (30.6%), followed by other unspecified challenges (28.6%); a lack of administrative support was the least cited barrier (6.1%) (Table 10). Because this item permitted more than one response per participant, the reported counts sum to 49 responses across 48 participants. Neither the Tripoli nor the Misurata study asked an equivalent open barriers question; therefore, this finding cannot be directly compared with prior Libyan data. Broader regional comparisons are considered in Section 4.

Table 10 . Challenges to Implementing Biosafety Practices (N = 48 respondents; multiple responses permitted)

Challenge	n	%
Lack of training	15	30.6
Lack of equipment	17	34.7
Lack of administrative support	3	6.1
Other challenges	14	28.6

3.3 Field Assessment Findings (Direct Observation)

To complement the staff self-reported data, the research team conducted a structured on-site assessment of all 20 laboratories using the field checklistand operational definitions described in Table 1 (Section 2.4). The checklist findings are presented by domain in Tables 11–15, and Figure 1 provides a summary comparison of the mean compliance scores across the five domains.

Infrastructure

Ventilation that met our operational definition was adequate in 15 of 20 laboratories (75.0%), a designated area for handling hazardous samples existed in 13 (65.0%), clear warning signs were posted in 12 (60.0%), and marked emergency exits were present in only 9 (45.0%) (Table 11). Therefore, the basics of engineering and signage were present for most, but by no means all, facilities. The 60.0% figure for warning signs is a marked contrast with Tripoli, where proper biohazard signage at entrance doors was missing in 85.7% of laboratories (Ben Ashur et al., 2017), although the two studies did not define signage in quite the same way.

Table 11. Field Assessment of Laboratory Infrastructure (N = 20)

Infrastructure item	Yes, n (%)	No, n (%)
Adequate ventilation system	15 (75.0)	5 (25.0)
Designated areas for handling hazardous samples	13 (65.0)	7 (35.0)
Clear warning signs	12 (60.0)	8 (40.0)
Clearly marked emergency exits	9 (45.0)	11 (55.0)

Personal Protective Equipment

Gloves and coats were available in sufficient supply in 16 of 20 laboratories (80.0%), masks in all 20 (100.0%), and staff were seen using PPE correctly, per the operational definition in Table 1, in every laboratory visited (100.0%) (Table 12). Protective goggles, once again, were nowhere to be found not in a single laboratory. The 80.0% availability figure for gloves and coats is above the 64.8% routine use reported in Tripoli (Ben Ashur et al., 2017). Neither the Tripoli nor the Misurata team asked about goggles specifically; therefore, this particular gap has no local benchmark; it is, as far as we can tell, a finding new to the Libyan literature, and one we flag again in the Limitations (Section 6) as something future assessments should track. We also note that the 100.0% figure for correct PPE use is a perfect score, on an item scored only at the moment of the visit, and is discussed critically in Section 4 alongside the possibility that staff behavior changed because they were being observed.

Table 12. Field Assessment of Personal Protective Equipment (N = 20)

PPE item / practice	Yes, n (%)	No, n (%)
Availability of sufficient gloves	16 (80.0)	4 (20.0)
Availability of laboratory coats	16 (80.0)	4 (20.0)
Availability of protective goggles	0 (0.0)	20 (100.0)
Availability of masks	20 (100.0)	0 (0.0)
Proper use of PPE by staff	20 (100.0)	0 (0.0)

Biological Waste Management

The separation of biological waste from general waste, availability of dedicated hazardous waste containers, and disposal according to approved protocols were confirmed in 17 of the 20 laboratories (85.0%).

However, documented waste management records were available in only nine laboratories (45.0%) (Table 13), indicating that operational waste handling practices outpaced the corresponding record-keeping. This 85.0% operational compliance is markedly higher than the corresponding Libyan figures reported to date: in Tripoli, 77.6% of laboratories lacked proper waste segregation, and 82.1% lacked liquid biological waste disposal procedures (Ben Ashur et al., 2017), while in Misurata, only 10.9% of respondents believed that waste was disposed of according to required procedures (Rhouma et al., 2021). The gap between these earlier findings and the present results may reflect genuine improvement over time, differences between cities, or differences between staff-reported practices and independently observed practices. However, our data cannot determine which explanation accounts for the difference, and this issue is considered further in Section 4.

Table 13. Field Assessment of Biological Waste Management (N = 20)

Waste-management item	Yes, n (%)	No, n (%)
Separation of biological waste from general waste	17 (85.0)	3 (15.0)
Dedicated containers for hazardous waste	17 (85.0)	3 (15.0)
Waste disposal according to approved protocols	17 (85.0)	3 (15.0)

Waste-management item	Yes, n (%)	No, n (%)
Availability of waste-management records	9 (45.0)	11 (55.0)

Biosafety Training

Regular biosafety training was confirmed in 13 of 20 laboratories (65.0%). Training records were available in 11 laboratories (55.0%), training on incident management in 12 (60.0%), and training on emergency equipment use in 11 (55.0%) (Table 14). Both figures again compare favorably with prior Libyan data: in Tripoli, no formal biosafety training program was documented in 88.3% of laboratories and accident records were absent in 82.6% (Ben Ashur et al., 2017), while in Misurata, only 8.9% of technicians had been trained by their employer (Rhouma et al., 2021).

Table 14. Field Assessment of Biosafety Training (N = 20)

Training item	Yes, n (%)	No, n (%)
Regular biosafety training provided	13 (65.0)	7 (35.0)
Training records available	11 (55.0)	9 (45.0)
Training on incident management	12 (60.0)	8 (40.0)
Training on emergency equipment use	11 (55.0)	9 (45.0)

General Safety and Emergency Preparedness

This domain showed the weakest overall performance. Fire extinguishers were available in 11 laboratories (55.0%), while emergency equipment, such as safety showers, was present in only five (25.0%). Clear emergency plans were documented in seven laboratories (35.0%), and incident-reporting procedures were available in nine laboratories (45.0%) (Table 15). The 55.0% fire-extinguisher availability found here is somewhat lower than the 70.4% reported in Tripoli, although only 32.1% of Tripoli staff knew the location of emergency equipment when it was present (Ben Ashur et al., 2017), a distinct but related indicator that was not assessed in the present checklist.

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ISSN: 2709-0345
مجلة روافد المعرفة
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Table 15. Field Assessment of General Safety and Emergency Preparedness (N = 20)

Safety item	Yes, n (%)	No, n (%)
Availability of fire extinguishers	11 (55.0)	9 (45.0)
Emergency equipment (e.g., safety showers)	5 (25.0)	15 (75.0)
Clear emergency plans available	7 (35.0)	13 (65.0)
Incident-reporting procedures available	9 (45.0)	11 (55.0)

Averaging the four items within each domain, the mean on-site compliance ranged from 40.0% for general safety and emergency preparedness to 75.0% for biological waste management, with infrastructure at 61.25%, PPE at 72.0%, and training at 58.75% (Figure 1). Across every domain for which a comparable indicator was available in the two previous Libyan facility studies, the mean compliance in Tarhuna equalled or exceeded the corresponding figures reported for Tripoli or Misurata (Ben Ashur et al., 2017; Rhouma et al., 2021). General safety and emergency preparedness remained the weakest domains overall and were consistently low across the three Libyan studies, consistent with the broader regional pattern discussed in Section 4.

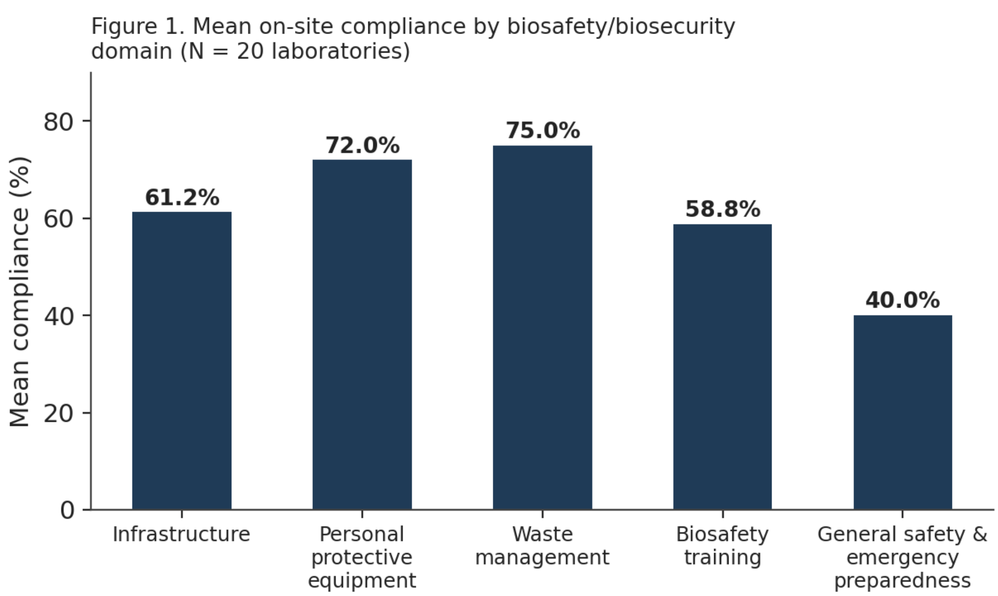

Figure 1. The values represent the unweighted mean of the "Yes" percentages for the items listed in Tables 10-14 for each domain.

4. Discussion

This is the third published facility-based assessment of biosafety and/or biosecurity practices in Libya, following the Tripoli (Ben Ashur et al., 2017) and Misurata (Rhouma et al., 2021) assessments, and the first to specifically assess laboratories in Tarhuna, Libya. The overall picture is mixed rather than uniformly favorable or unfavorable: practices relevant to routine specimen handling, particularly glove use and mask availability, were common, whereas eye protection, emergency preparedness, and record-keeping showed significant gaps. Section 3 shows that Tarhuna's findings generally matched or exceeded those of Tripoli and Misurata, where meaningful comparisons could be made. The following discussion considers each domain in relation to the two previous Libyan studies before placing the findings in a wider regional and international context.

Training showed a relatively favorable pattern. Three-quarters of the Tarhuna staff (75.0%) reported having received biosafety or biosecurity training, and independent field checks confirmed regular documented training in 65.0% of the laboratories (Tables 6 and 14). These figures were higher than those reported in Tripoli, where 88.3% of technicians had received no formal biosafety training (Ben Ashur et al., 2017), and Misurata, where only 8.9% of graduated technicians reported having received training from an employer, and biorisk management was reported less frequently as a component of university coursework (Rhouma et al., 2021). The Misurata study addressed a somewhat different aspect, particularly university-level biosecurity education rather than workplace biosafety training; therefore, the comparison was indirect. Nevertheless, both previous studies indicate limited training coverage in relevant laboratory settings in Libya, against which the findings from Tarhuna appear relatively favorable. This issue is not unique to Libya. Formal fire-emergency training reached only 5.2% of laboratories surveyed in Khartoum State, Sudan (Elduma, 2012), while a later Khartoum study reported that biosafety practice scores remained below internationally recommended levels despite better awareness (Alam et al., 2022). In Sudan, Egypt, and Saudi Arabia, a study of government laboratory personnel similarly identified a gap between knowledge and practice (Ahmed et al., 2022), while in Morocco, only 17.4% of laboratory workers had received formal training despite relatively good general knowledge scores (Bajjou et al., 2019). Taken together, these findings suggest that training coverage varies across laboratory settings in the region and remains an area requiring sustained attention. However, we were unable to formally test whether training status was statistically associated with better compliance. The available dataset recorded training and compliance as separate aggregate counts rather than linked laboratory- or staff-level records; therefore, a valid chi-square or similar test could not be performed. This represents an analytical limitation rather than a null finding, which is discussed in Section 6.

The complete absence of protective goggles, with no staff member reporting their use and no laboratory having them available (Tables 7 and 12), was one of the most notable findings of the study. This finding could not be directly compared with earlier Libyan studies because neither the Tripoli nor Misurata assessments specifically evaluated protective eyewear. However, the two studies assessed broader PPE use. In Tripoli, routine glove-and-coat use was reported by 64.8% of technicians, with 8.2% reporting that they never used either item (Ben Ashur et al., 2017), compared with universal glove use and 70.8% coat use among staff in the present study. We deliberately avoided attributing the absence of goggles to a single cause because the present study did not directly assess the reasons for their absence. Potential explanations include limited procurement or availability, differences in risk perception, the extent to which eye protection is emphasized in local procedures, and competing resource priorities. These possibilities would require a dedicated follow-up assessment, such as interviews with laboratory managers regarding procurement and PPE policies, to distinguish among them. The present findings support the need to consider eye protection as part of risk-based PPE selection, particularly where splash or aerosol exposure is possible. WHO guidance identifies PPE, including safety glasses and goggles, as potential barriers against exposure, with the type of PPE determined by the biological agent, activity, exposure route, and risk assessment (WHO, 2020). Similar limitations in access to protective barriers and biosafety equipment have been reported among clinical laboratory staff in Ethiopia (Tadesse et al., 2025), while PPE practices were inconsistently applied among medical laboratory students in Uganda (Padde et al., 2022). The absence of protective goggles therefore represents a potentially modifiable gap that should be explicitly assessed in future laboratory biosafety evaluations in Libya.

Another issue is the difference between staff self-reports and direct field observations, particularly for PPE. On self-report, 100.0% of the staff reported using gloves (Table 7), whereas field observation found that only 80.0% of laboratories had a sufficient glove supply available (Table 12). These measures are not directly equivalent; the former reflects individual behavior as reported by the staff, whereas the latter reflects facility-level availability observed by the research team during a single visit. Nevertheless, this difference is noteworthy. More strikingly, field observations recorded correct PPE use, according to the operational definition in Table 1, in 100.0% of the laboratories (Table 12). Because this measure was based on behavior observed at a specific time of the visit, it should be interpreted cautiously. The possibility of an observation-related change in behavior cannot be excluded, particularly because the checklist was completed openly by a visiting research team rather than through covert or blinded observations. Thus, some of the high compliance recorded during the visit, particularly for PPE use, may not fully represent routine practice on other days. This possibility should be considered when interpreting the 100.0% correct-use finding and is acknowledged as a limitation of the observational approach in Section 6 of this paper.

Waste management showed a similarly favorable pattern, although documentation lagged behind the observed practice. Operational compliance in Tarhuna reached 85.0% for waste segregation, availability of dedicated hazardous-waste containers, and disposal according to approved protocols (Table 13). This was higher than the corresponding findings reported from Tripoli, where 77.6% of laboratories lacked proper waste segregation and 82.1% lacked liquid-waste disposal procedures (Ben Ashur et al., 2017), and from Misurata, where only 10.9% of respondents believed that waste was disposed of according to required procedures (Rhouma et al., 2021). Documentation was substantially less complete: only 45.0% of Tarhuna laboratories could produce waste management records (Table 13), similar to the documentation gap reported in Tripoli, where accident records were missing in 82.6% of laboratories (Ben Ashur et al., 2017). This discrepancy between observed practice and available documentation is not necessarily unique to Libya. An integrated assessment of clinical microbiology laboratories in Lubumbashi, Democratic Republic of the Congo, found written standard operating procedures in only 45% of laboratories despite higher rates of routine PPE use (Kabamba-Tshikongo et al., 2026), while in Togo, laboratories scored considerably better on practice (77.6% good) than on knowledge (49.1% good) (Halatoko et al., 2024). Together, these findings suggest that operational practices and formal documentation or knowledge may not always develop at the same pace.

General safety and emergency preparedness was the weakest domain in the present assessment, with a mean compliance across fire extinguishers, emergency equipment, emergency plans, and incident-reporting procedures of only 40.0% (Table 15, Figure 1). Fire extinguishers were available in 55.0% of the laboratories in Tarhuna, compared with 70.4% in Tripoli. However, the Tripoli assessment also found that only 32.1% of staff knew where fire extinguishers were located (Ben Ashur et al., 2017), an aspect not assessed by our checklist. Similar weaknesses have been reported in other African countries. Engineering controls and administrative systems were among the weakest categories in the Parakou, Benin veterinary laboratory assessment (Sodjinou et al., 2021), whereas infrastructure and emergency preparedness were identified as priority gaps in Lubumbashi (Kabamba-Tshikongo et al., 2026). Taken together with the Libyan findings, these results suggest that emergency and administrative preparedness may represent a persistent regional weakness and an important area for improvement in Tarhuna's healthcare system.

The difference between staff perceptions and direct field findings warrants consideration. In the present study, 85.4% of respondents believed that their laboratory had adequate biosafety infrastructure (Table 9), whereas field verification yielded an infrastructure compliance score of 61.25%, and general safety and emergency preparedness scored only 40.0% (Tables 11 and 15, Figure 1). Depending on the comparison, this represents a difference of approximately 24–45 percentage points between staff perceptions and the corresponding field assessment domains. This discrepancy may partly reflect the differences between perceived overall adequacy and the specific operational criteria assessed by the checklist. It may also be influenced by the same observation and social desirability considerations discussed above. Neither Tripoli nor Misurata included a directly comparable perception measure in their surveys. However, a similar mismatch between positive self-assessment and weaker measured performance has been reported among university laboratory staff in Malaysia, where attitudes toward biosafety were rated as good (95.5%), while measured knowledge was only moderate (74.8%) (Nik Mohd Razali et al., 2025). These findings suggest that staff perceptions should not be interpreted as substitutes for objective facility-level assessments. Instead, differences between perceived and observed conditions may help identify areas where additional assessments, training, or resource allocation is warranted.

The main barriers identified by staff in the present study–lack of equipment (34.7%) and lack of training (30.6%) (Table 10)–are consistent with concerns reported elsewhere. In Misurata, more than 60% of respondents called for additional security staff and clearer institutional procedures, reflecting concerns regarding resources and administrative support (Rhouma et al., 2021). Outside Libya, a survey of Pakistani biomedical laboratory workers found that practical workplace-level barriers, including insufficient time and limited authority to change established practices, were more important than a simple lack of awareness (Shakoor et al., 2016). Taken together, these findings suggest that some of the biosafety and biosecurity gaps observed in Tarhuna may not be unique to the city but may reflect broader resource, training, and organizational constraints reported across Libya and the surrounding region.

These findings should also be considered in the context of Libya’s evolving regulatory framework. At the time of the 2018 Joint External Evaluation, Libya had no binding national legislation on laboratory biosafety and biosecurity, and no single body had been assigned the responsibility of enforcing the existing guidance (WHO, 2019). The 2021 Global Health Security Index similarly identified important gaps (NTI et al., 2021). Since then, the Libyan National Committee for Biosafety and Bioethics has approved a national document outlining the requirements related to biosafety and bioethics review (Libyan National Committee for Biosafety and Bioethics, 2022). This document postdates the Tripoli and Misurata studies but predates the current study. Although this temporal sequence is noteworthy, the cross-sectional design of the present study and the absence of longitudinal or comparative data do not allow us to determine whether the newer regulatory framework contributed to the more favorable findings observed in Tarhuna than in Benghazi. Nevertheless, the persistence of gaps in eye protection and emergency preparedness indicates that the existence of a national regulatory framework does not necessarily translate into consistent laboratory-level implementation. The 2026 WHO Regional Office for the Eastern Mediterranean mission to Libya's public health laboratory system also identified biosafety, biosecurity, and workforce capacity as continuing priorities (WHO Regional Office for the Eastern Mediterranean, 2026), which is broadly consistent with the facility-level gaps identified in this study.

5. Conclusion and Recommendations

Diagnostic laboratories in Tarhuna demonstrated relatively favorable performance in several aspects of routine biosafety practices, but important gaps remained in specific areas. Core specimen-handling practices were generally well established, with glove use reported by 100.0% of the staff, while PPE availability and correct use were high during the field assessment (Tables 7 and 12). However, these findings should be interpreted with the potential influence of direct observation in mind, as discussed in Section 4 of this paper. Three priority gaps were identified: complete absence of protective goggles (0.0% in both staff self-report and field assessment; Tables 7 and 12), weak general safety and emergency preparedness (40.0% mean compliance, the lowest of the five domains; Table 15, Figure 1), and a substantial difference between staff perceptions of infrastructure adequacy (85.4%; Table 9) and field-verified compliance (61.25% for infrastructure and 40.0% for general safety and emergency preparedness; Tables 11 and 15). These findings indicate that improvement efforts should focus not only on routine PPE practices but also on less consistently addressed aspects of laboratory safety, particularly eye protection, emergency preparedness, infrastructure, training, and proper documentation. Laboratory management should ensure the procurement and routine availability of appropriate protective goggles or other suitable eye protection for activities involving potential splash or aerosol exposure and incorporate eye protection into laboratory PPE policies and staff training. Emergency preparedness should be strengthened through the provision and maintenance of fire extinguishers and other emergency equipment, clearly marked emergency exits, written emergency response procedures, and appropriate incident reporting systems, with emergency procedures communicated to all laboratory staff and reviewed periodically. Regular and documented biosafety and biosecurity training should be established for laboratory personnel, including refresher training for existing staff and orientation for newly appointed personnel, with an emphasis on the practical application of biosafety procedures rather than theoretical knowledge alone. Laboratories should also strengthen the documentation of waste management, staff training, incidents, and emergency procedures through standardized records and checklists to ensure that appropriate practices are consistently documented and available for internal review and external assessment. Relevant health authorities and laboratory management should support periodic facility-based assessments using standardized biosafety and biosecurity checklists, preferably by combining staff self-reports with direct observation and documentary verification. Laboratories with deficiencies in ventilation, hazardous sample handling areas, warning signage, emergency exits, or other infrastructure should develop prioritized corrective action plans based on risk assessment and available resources. Future studies should include linked laboratory- and staff-level datasets to permit valid inferential analyses of factors associated with biosafety compliance. Larger multicenter studies involving additional Libyan cities would be valuable in determining whether the patterns observed in Tarhuna are representative of diagnostic laboratories elsewhere in Libya. Overall, the findings indicate that Tarhuna's diagnostic laboratories have established several important routine biosafety practices; however, further improvement is required in eye protection, emergency preparedness, infrastructure, training, and documentation. Addressing these gaps through targeted interventions, regular monitoring, and appropriate institutional support could strengthen biosafety and biosecurity practices and contribute to safer diagnostic laboratory environments in Tarhuna and other regions of Libya.

6. Limitations

Several limitations should be considered when interpreting these findings. First, no comprehensive, up-to-date sampling frame of all diagnostic laboratories operating in Tarhuna was available at the time of the study. Therefore, a formal probability sample from the full laboratory population could not be drawn, the sampling fraction could not be calculated, and the representativeness of the 20 participating laboratories could not be established. Second, laboratory selection was random within an accessible and consenting pool, whereas staff selection was availability-based, including eligible staff who were present and willing to participate on the day of the visit. Consequently, staff-level findings may be subject to selection bias. Third, the questionnaire and field checklist were developed from WHO and CDC/NIH guidance and previous Libyan studies but were not based on a single validated instrument, were not formally piloted, and were not subjected to reliability testing. Fourth, the checklist did not assess biosafety-cabinet availability or advanced biosecurity measures such as restricted access, inventory control, surveillance, or personnel reliability screening; therefore, conclusions regarding biosecurity should be limited to the items actually assessed. Fifth, the available dataset consisted of aggregate item-level counts rather than linked laboratory- or staff-level records, preventing valid inferential analyses such as chi-square or Fisher's exact tests. Sixth, field observations were conducted openly by the research team; therefore, the Hawthorne effect cannot be excluded, particularly for the 100.0% correct-PPE-use finding. In addition, self-reported questionnaire responses may have been affected by social-desirability bias, although the field assessment provided some degree of triangulation. Finally, the cross-sectional design prevents assessment of temporal trends or causal relationships and does not allow determination of whether differences from previous Libyan studies reflect genuine improvement, differences between cities, or differences in measurement methods. One questionnaire item (Table 10) allowed multiple responses per participant; therefore, its percentages should be interpreted accordingly.

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