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Building a Culture of Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences: A View from Mali

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ABSTRACT

Adherence to biosafety and biosecurity standards and practices by those involved in the life sciences is essential to protecting the health of humans, animals, and the environment. Fostering a culture of responsibility is one of the underlying tenets of the Biological Weapons Convention, the Global Health Security Agenda, Joint External Evaluation of International Health Regulations, and the Global Partnership Against the Spread of Weapons and Materials of Mass Destruction. It also underpins national and international efforts to protect science from misuse and to protect workers and the public from laboratory incidents. Unlike the nuclear domain, there is no available guidance or unified perspective on the nature of this culture or how it may be assessed. The International Working Group on Strengthening the Culture of Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences developed a framework to assess organizational culture in biological laboratories based on the model developed by the International Atomic Energy Agency for nuclear facilities. This framework encompasses 1) management systems; 2) behavior of leadership and personnel; 3) principles for guiding decisions and behaviors; and 4) beliefs, opinions and attitudes. Here we present an example of how the beliefs, opinions, and attitudes element was employed to assess the organizational culture of laboratorians from five regions in Mali. This is the first assessment using the framework and, as such, provides a model for others seeking to improve biosafety and biosecurity, and may ultimately lead to international harmonization of this concept and provide a pathway to strengthen Mali's laboratory system.

Keywords: Biosafety; Biosecurity; Mali; Responsible Conduct; Organizational Culture.

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INTRODUCTION

State of Biosafety and Biosecurity Implementation Activities Worldwide

As highlighted by the COVID-19 pandemic, biological incidents—whether naturally occurring, accidental, or deliberate in origin—have the potential to cause widespread, long-term, and multisectoral ramifications across the globe. The 2019 Global Health Security Index report concluded that, “countries are not prepared for a globally catastrophic biological event, including those that could be caused by the international spread of a new or emerging pathogen or by the deliberate or accidental release of a dangerous or engineered agent or organism. Biosecurity and biosafety are under-prioritized areas of health security, and the connection between health and security-sector actors for outbreak response are weak” [1].

Furthermore, “81% of countries score in the bottom tier for indicators related to deliberate risks (biosecurity), 66% of countries score in the bottom tier for indicators related to accidental risks (biosafety), and fewer than 5% of countries provide oversight for dual-use research” [1]. Establishing a strong culture of biosafety and biosecurity and responsible conduct is one of the fundamental risk management approaches for protecting against these threats.

Efforts to Strengthen the Culture of Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences

By strengthening the culture of biosafety, biosecurity, and responsible conduct in the life sciences, the benefits of scientific research can be effectively realized while minimizing the potential for misuse. The Biological Weapons Convention (BWC), Global Health Security Agenda (GHSA), Joint External Evaluation (JEE) of International Health Regulations (IHR), and G7 Global Partnership against the Spread of Weapons and Materials of Mass Destruction (G7GP) all include the culture of biosafety, biosecurity, and responsible conduct in the life sciences as underlying tenets [2].

The BWC is the cornerstone of the biological weapons disarmament and nonproliferation regime and implicitly requires a sense of responsibility among those conducting dual-use research. The Final Declarations of the Seventh and Eighth Review Conferences both, “encourage the promotion of a culture of responsibility amongst relevant national professionals,” as well as the, “voluntary development, adoption, and promulgation of codes of conduct.” However, there is no detailed description of mechanisms by which to accomplish such self-regulation or normalization of responsible conduct [3].

GHSA also addresses an international culture of responsibility. The GHSA objectives, largely aimed at capacity building, are divided into multiple action packages. Action Package Prevent 3: Biosafety and Biosecurity promotes, “a shared culture of responsible conduct of life science research and oversight of dual-use risks” [4]. Moreover, the JEE tool adopted by the World Health Organization (WHO) in 2016 provides countries with a mechanism for systematic, multisectoral evaluation of the IHR technical areas, including national biosafety and biosecurity capacities [5].

In addition to the BWC and GHSA, the G7GP is committed to countering biological weapons and bioterrorism and includes, as one of its deliverables on biosecurity, collective programming efforts and activities aiming to, “reduce biological proliferation risks through the advancement and promotion of safe and responsible conduct” [3]. The 2021 G7 Non-Proliferation Directors statement commits to, “addressing challenges posed by dual-use research of concern (DURC) and promoting an environment in which science and technology advances and legitimate research collaboration can flourish” [6].

Although these international treaties, partnerships, and initiatives help to establish international norms and have the potential to strengthen an international culture of biosafety, biosecurity, and responsible conduct in the life sciences, none offer a detailed discussion of what defines a culture of responsibility and how culture change initiatives can be measured and evaluated [3].

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However, efforts are underway, spearheaded by a community of practice comprised of volunteer representatives of governments, academia, industry, the do-it-yourself biology community, non-governmental, and professional, international, and intergovernmental organizations, which gather under the banner of the International Working Group on Strengthening the Culture of Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences (IWG). The IWG was established on the foundation of the U.S. interagency Federal Experts Security Advisory Panel (FESAP) Working Group which endeavored to, "create and strengthen a culture that emphasizes biosafety, laboratory biosecurity, and responsible conduct in the life sciences," as a follow up to the 2014 laboratory incidents in the U.S. and the White House subsequent tasking to the FESAP to undertake a comprehensive review and to identify specific recommendations to strengthen biosafety and biosecurity practices and oversight of federally funded research activities [3].

The IWG developed an agreed upon definition on what culture is in the context of biosafety and biosecurity, defined training goals and objectives, and developed guiding principles to promote a culture of biosafety, biosecurity, and responsible conduct in the life sciences, among other activities [7]. Furthermore, the IWG developed a methodology, the Culture of Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences (Self) Assessment Framework (Framework) to assess organizational culture in biological laboratories based on the model developed by the International Atomic Energy Agency for nuclear facilities [8]. This Framework incorporates four elements (or principles) identified as core components for a culture of biosafety, biosecurity, and responsible conduct in the life sciences. These elements include 1) management systems; 2) behavior of leadership and personnel; 3) principles for guiding decisions and behaviors; and 4) beliefs, opinions and attitudes.

Recent policy documents, such as the WHO Laboratory Biosafety Manual 4th Edition, have advocated that a critical component of maintaining laboratory biosafety and biosecurity protocols relies on conducting periodic threat, vulnerability, and risk assessments [9]. The IWG Framework provides such a mechanism for organizations, such as laboratories or biomedical facilities, to assess the state of their organizational biosafety and biosecurity culture based on specific elements of the organizational culture model. The Framework can be used in its entirety or one or more of its four constituent elements may be used. As described the preface to the Framework, other tools have different aims and purposes and may have areas overlapping with this Framework (e.g. WHO's JEE, ISO 35001:2019 Biorisk management for laboratories and other related organizations) [5,10].

Organization of the Healthcare System and Laboratory Network in Mali

According to Mali's 2016-2020 National Strategic Plan for Essential Care in the Community, the healthcare system is currently organized in a pyramidal and hierarchical manner with 1,151 community health centers (CSCOM) at its base [11]. These centers constitute the first level of contact for the population and offer a minimum package of services. Three reference levels of CSCOMs are:

1. Level 1: Referral Health Centers (CSREF) offer referral care including the management of medical and surgical emergencies. The CSREFs are located at the district level;
2. Level 2: comprised of general hospitals known as Regional Hospitals; and
3. Level 3: hospitals that offer general and specialized care.

Mali's laboratory network mirrors the health system structure. There are corresponding diagnostic laboratories with increasing diagnostic capacities respectively: CSCOMs, CSREFs laboratories (Level 1), regional hospitals laboratories (Level 2), and specialized hospital laboratories as well as national reference laboratories (Level 3) [11].

Several organizations and partnerships have strengthened Malian laboratories' management of biological risks and resulted in increased awareness about the importance of biosafety and biosecurity among Malian lab workers. For example, the Malian Association for Biosafety and Biosecurity has stimulated biological risk management since its creation in 2011 through

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international collaborations, such as the G7GP, GHSA, and the International Twinning Program of Sandia National Laboratories (SNL). Malian lab workers from human, veterinary, and agricultural National Reference Laboratories also attended training courses offered by SNL, the International Federation of Biosafety Associations, and the Middlebury Institute of International Studies at Monterey's James Martin Center for Nonproliferation Studies. The training courses focused on the development of biosafety and biosecurity frameworks and regulatory documents. Upon completion of these courses, many of the graduates served later as trainers for others in their organization. Mali participated in the consultative process organized by Africa CDC and WHO to identify regional priorities for biosafety and biosecurity and, as a Member State of Africa CDC contributes and participates in the implementation of its Biosafety and Biosecurity Initiative and the 2021-2025 Strategic Plan [12, 13, 14].

The Nexus of Biosafety, Biosecurity, and National Security Threats in Mali

Implementation of biosafety and biosecurity measures in Mali are notable given its current national security challenges and the state of its laboratory infrastructure. For years, Mali has dealt with geopolitical unrest and terror activity. Additionally, Mali scored a 1 and 2 out of a possible 5 on the two biosafety and biosecurity indicators, which assess in-country capacity of biosafety and biosecurity systems and laboratory training and practices, on its most recent JEE [15].

For many years, Mali was an example of a successful African democracy [16]. However, periods of instability in Mali's northern region stemming from the Tuareg rebellion culminated in a 2012 military coup d'état. The coup sparked a decade defined by political power-shifts, heightened security challenges, and an elevated threat from terrorist actors [17]. Since then, Mali has battled to combat malign actors and secure the safety of its citizens. The 2019 Country Reports on Terrorism notes that Mali is now a member of the G5 Sahel Joint Force, which was launched in 2017 to coordinate counterterrorism operations in Mali, Burkina Faso, Chad, Mauritania, and Niger. The G5 Sahel is not yet capable of disrupting the growing terrorist footprint across the Sahel, which includes affiliates of al-Qa'ida, ISIS, and non-aligned groups, but has potential as a coordination mechanism [18]. Despite these efforts, Mali has yet to restore its national security to the level it was prior to the 2012 coup d'état.

Furthering public health capabilities and preventing biological threats are essential to national security. Expansion of laboratory biosafety and biosecurity best practices are key ways to strengthen public health capacity, to mitigate unintentional and intentional biological incidents, and, in turn, strengthen a country's national security [19]. Enhancing responsible conduct among laboratory workers is paramount to bolstering biosafety and biosecurity measures because it provides a flexible, implementable, and low-cost mechanism for preventing accidental disease outbreaks and mitigating the deliberate misuse of science for nefarious purposes.

This baseline assessment provides an opportunity to: assess how actions should be prioritized in order to minimize laboratory-acquired infections, incidents, and near misses; ensure that biosafety, biosecurity, and responsible conduct receive appropriate attention; increase laboratory staff members' commitment to biosafety and biosecurity; minimize the risk that science and technology could be misused; and promote biosafety and biosecurity norms, values, and beliefs of the entire life sciences profession including biological weapons prohibition.

METHODOLOGY

IWG (Self) Assessment Framework Survey

A French version of the IWG's Framework described earlier was developed in collaboration with the Public Health Agency of Canada and used in this study [8]. The Framework consists of four sections addressing the following topic areas: 1) management systems; 2) behavior of leadership and personnel; 3) principles for guiding decisions and behaviors; and 4) beliefs, opinions and attitudes. The Framework also includes a survey specific to each section. This study focuses only on beliefs, opinion, and attitudes because of the lack of existing assessments looking at how these factors influence biosafety, biosecurity, and responsible conduct. Therefore, the Framework's

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20-question survey designed to assess beliefs, opinions, and attitudes among laboratory workers about biosafety and biosecurity—including sentiments about DURC and cyberbiosecurity—was used for this study. In light of the COVID-19 pandemic, one additional question was added to the survey for the purposes of this study (Q21: COVID-19 is a natural disease). Laboratory workers were asked to individually answer the 21 questions (**Table 1**) of the survey and return the completed survey to the National Institute of Public Health in Bamako, Mali.

The survey was administered to 104 laboratory personnel across 64 laboratories distributed amongst five regions of Mali (Kayes, Koulikoro, Sikasso, Segou, and Mopti/Northern Region). A French language hard copy of the survey was distributed to laboratory workers during biosafety and biosecurity training sessions in the context of COVID-19 on the following dates: 24 November 2021 in Segou and Mopti/Northern Region, 01 December 2020 in Sikasso, 08 December 2020 in Kayes, and 21 December 2020 in Koulikoro. Before starting each training session, the trainers presented the questionnaire to all the laboratory workers across the human, animal, and agricultural health sectors. Each laboratory worker who participated in the survey completed the questionnaire individually over a 30 to 60-minute timeframe. The data was subsequently uploaded to, and analyzed in, Microsoft Excel. Ten participants were excluded from analysis for omitting six or more survey questions (omitted>25% of survey questions). Therefore, the total n-value for this study is 94 (n=94). A visual depiction of the methodology used to collect data can be found in **Figure 1**.

Data Analysis

Due to the varying number of lab workers who responded to the survey across the five study regions, average values were used to analyze the data collected. When conducting the following analyses, survey responses with a value of zero were not included. In the IWG's Framework, a response of zero denotes, "N/A or I don't know." In order to prevent responses with zero values from skewing the data, these values were excluded from data analysis.

Within each region, lab workers' scores for each survey question were averaged, resulting in each region having 21 scores (e.g., one for each question of the survey), known as the Survey Question Averages. These scores were: 1) averaged within each region to create a single value, called the Overall Regional Average and, 2) averaged with identically matched survey questions across regions to yield a single value for each of the 21 survey questions, known as the Combined Question Average (**Table 2**).

Each study region's 21 Survey Question Averages were ranked from highest to lowest. The scores were then partitioned into three tiers (Tier I: The seven highest-ranked Survey Question Average scores in each of the five study regions; Tier II: The seven middle-ranked Survey Question Average scores in each of the five study regions; and Tier III: The seven lowest-ranked Survey Question Average scores in each of the five study regions). The distribution of survey questions across Tiers I-III informed identification of opportunities and potential gaps.

RESULTS

There were a total of 94 laboratory workers who responded to the survey across five regions of Mali [Kayes: 20 laboratory workers (21.28% of total study population) across 13 laboratories; Koulikoro: 20 laboratory workers (21.28%) across 15 laboratories; Sikasso: 20 laboratory workers (21.28%) across 12 laboratories; Segou: 18 laboratory workers (19.15%) across 11 laboratories; Mopti/Northern Region: 16 laboratory workers (17.02%) across 13 laboratories]. There was an average of 1.5 (range 1 to 4) laboratory workers from each lab and an average of 19 (range 16 to 20) laboratory workers from each region. Kayes, Koulikoro, Sikasso, Segou, and Mopti/Northern Region reported Overall Regional Average scores of 3.98, 3.79, 4.01, 3.78, and 3.98, respectively. These scores did not show any large regional differences between beliefs, opinions, and attitudes of Malian laboratory workers (σ=.10; σ^2 =.01). These values, each region's Survey Question Averages, and Combined Question Averages are detailed in **Table 2**.

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Table 1: International Working Group on Strengthening the Culture of Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences (Self) Assessment Framework's Survey Questions Assessing Beliefs, Opinions, and Attitudes.

Survey Questions – Beliefs, Opinions, and Attitudes
Q1. There is a risk of bioterrorism or an attack with a biological weapon.
Q2. Controlling access to sensitive information is integral to biosecurity.
Q3. I understand the importance of trustworthiness determination.
Q4. My organization provides training on identifying symptoms of high-risk behavior in oneself and in others.
Q5. Biosafety and/or biosecurity deficiencies or vulnerabilities are corrected with a sense of urgency.
Q6. I take professional pride in my work.
Q7. My organization and its members encourage teamwork and cooperation.
Q8. Biosafety and biosecurity infractions are handled appropriately.
Q9. My organization cares more about biosafety than about the results of our work.
Q10. I am aware that there are ethical, legal, and societal issues and consequences attached to my research.
Q11. Technical expertise and experience underpin the assurance of future biosafety performance.
Q12. In my organization, individuals have appropriate competency to perform their assigned tasks and to work safely and effectively.
Q13. My organization has a culture that supports and encourages trust, collaboration, consultation, and communication with regard to biosafety and biosecurity.
Q14. National policy and legislation relevant to the life sciences aim to provide protection against the misuse of science.
Q15. Risk assessments are important tools to identify areas of improvement and specific measures for reducing risk, including the level of containment required.
Q16. I believe that it is important to report not only laboratory accidents and incidents but also near misses.
Q17. I have received adequate training on the procedures necessary to conduct my work without compromising safety and security.
Q18. I have adequate PPE available for me to perform my work safely and securely.
Q19. Scientists have an obligation to do no harm.
Q20. I do/would/will report my concerns to the appropriate people, authorities, and/or agencies if I become aware of activities that violate the Biological and Toxin Convention, United Nations Security Council resolution 1540, or international customary law.
Q21. Covid-19 is a natural disease.

Response options for each question: 0 = N/A or I don't know; 1 = Strongly Disagree; 2 = Disagree; 3 = Neither Agree or Disagree; 4 = Agree; 5 = Strongly Agree; Note: Q21 was added to the survey for the purposes of this study.

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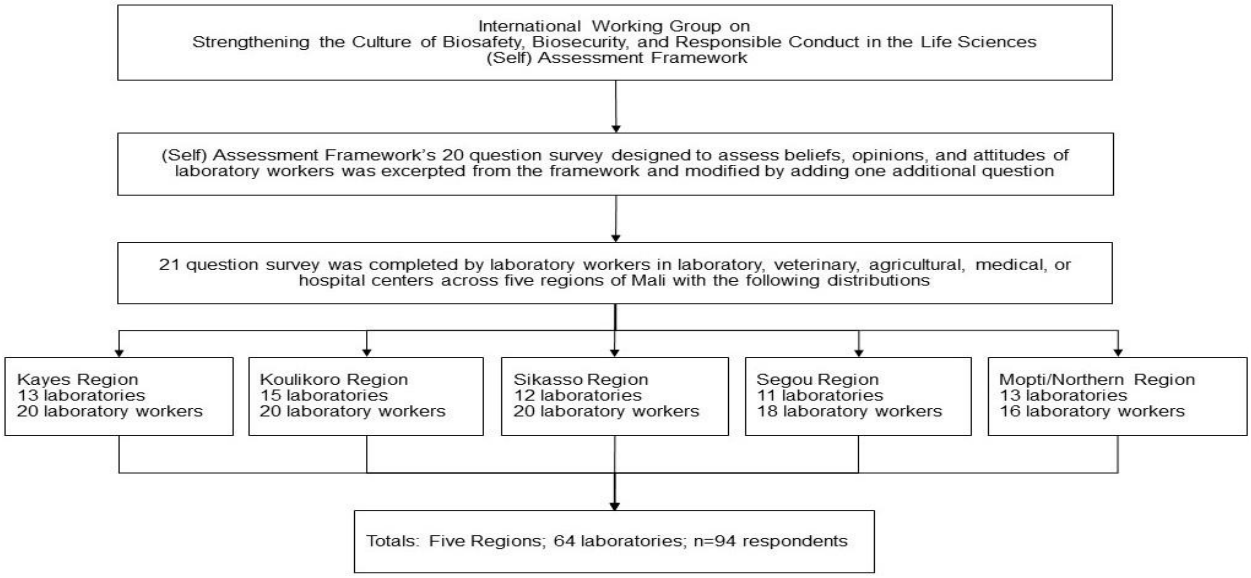

Figure 1: Data Collection Methodology to Assess Beliefs, Opinions, and Attitudes of Laboratory Workers across Five Regions of Mali.

Based on the Combined Question Averages in **Table 2**, Q21, Q9, and Q4 were lowest-ranked questions with scores of 2.83, 2.86, and 3.13, respectively. The three questions with the highest-ranked Combined Question Average scores based on the values in **Table 2** are Q6, Q16, and Q2, with scores of 4.56, 4.49, and 4.32, respectively.

Survey questions in Tier I and Tier III demonstrate the highest-ranked and lowest-ranked questions across the five regions based on Survey Question Average values. They also represent the strongest beliefs, opinions, and attitudes. Therefore, only Tier I and Tier III were used for further analysis. To adjust for potential outliers, only questions that appeared in a majority of the regions (e.g., three or more regions) in Tier I and Tier III were considered. Dividing the data in this manner demonstrated Q1, Q3, Q6, Q15, Q16, Q19, and Q20 were ranked the highest most frequently, as evidenced by them appearing in Tier I in the majority (e.g., three or more) of the study regions. Breaking down the data in this way also showed that Q4, Q5, Q8, Q9, Q18, and Q21 were the lowest-ranked scores most frequently, since they appeared in Tier III in the majority of the study regions (e.g., three or more).

A full breakdown of each region's questions partitioned into the three Tiers as described in the Methods section is displayed in **Figure 2**.

DISCUSSION

Inferences about beliefs, opinions, and attitudes of lab workers in Mali can be made by examining each region's Survey Question Averages when partitioned into three tiers: Tier I (the seven highest-ranked Survey Question Average scores among lab workers in Kayes, Koulikoro, Sikasso, Segou, and Mopti/Northern Region, respectively), Tier II (the seven middle-ranked Survey Question Average scores among lab workers in Kayes, Koulikoro, Sikasso, Segou, and Mopti/Northern Region, respectively), and Tier III (the seven lowest-ranked Survey Question Average scores among lab workers in Kayes, Koulikoro, Sikasso, Segou, and Mopti/Northern Region, respectively). Tier I and Tier III are of particular interest since they comprise the highest and lowest-ranked Survey Question Averages across the five regions,

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Table 2: Lab Worker Survey Question Averages, Overall Regional Averages, and Combined Question Averages.

Question	Survey Question Average (Kayes)	Survey Question Average (Koulikoro)	Survey Question Average (Sikasso)	Survey Question Average (Segou)	Survey Question Average (Mopti/Northern Region)	Combined Question Average
Q1	4.41	4.24	4.43	3.25	4.00	**4.07**
Q2	4.26	4.31	4.42	4.06	4.53	**4.32**
Q3	4.27	4.20	4.26	4.24	4.40	**4.27**
Q4	3.25	2.93	3.20	3.27	3.00	**3.13**
Q5	3.75	3.38	4.00	3.28	4.19	**3.72**
Q6	4.25	4.80	4.65	4.61	4.50	**4.56**
Q7	3.95	4.20	4.11	3.73	4.19	**4.04**
Q8	3.56	3.06	3.88	3.25	3.47	**3.44**
Q9	2.70	2.44	3.22	2.94	3.00	**2.86**
Q10	4.25	3.71	3.94	3.94	3.93	**3.95**
Q11	4.33	3.71	4.20	4.07	3.93	**4.05**
Q12	4.17	3.68	4.12	4.00	3.94	**3.98**
Q13	4.05	3.31	3.84	3.82	4.00	**3.81**
Q14	3.88	4.20	3.71	3.91	4.15	**4.08**
Q15	4.39	4.29	4.42	4.29	4.13	**4.31**
Q16	4.70	4.47	4.58	4.28	4.40	**4.49**
Q17	3.70	3.84	3.70	4.06	4.06	**3.87**
Q18	3.95	3.53	3.50	3.39	3.80	**3.63**
Q19	4.61	4.11	4.47	3.94	4.40	**4.31**
Q20	4.28	4.06	4.47	4.36	4.38	**4.31**
Q21	3.06	2.68	2.85	2.56	3.00	**2.83**
Overall Regional Average	**3.98**	**3.79**	**4.01**	**3.78**	**3.98**	

and therefore provide the most significant insight into the strongest-held beliefs, opinions, and attitudes held by laboratory workers in Mali (**Table 3**). The Tier I questions in **Table 3** suggest some general trends regarding the beliefs, opinions, and attitudes of Malian lab workers. Q3, Q16, and Q19 suggest that lab workers have a sense of personal responsibility to abide by proper biosafety and biosecurity practices. Q6 suggests that lab workers place high value on their professional work. Implementing proper biosafety and biosecurity practices is critical to carrying out high quality work in a laboratory environment, suggesting that lab workers may be open to the idea of further incorporating biosafety and biosecurity measures into their daily laboratory routines in order to execute their workplace responsibilities to the highest possible standards. Secondly, Q2, Q15, and Q20 suggest that laboratory workers are aware of biosafety and biosecurity best practices. Having this level of awareness suggests that laboratory workers are personally capable of implementing best practices during their daily work. Finally Q1 suggests Malian lab workers share a belief that they face a high threat from bioterrorism. These sentiments among laboratory workers are

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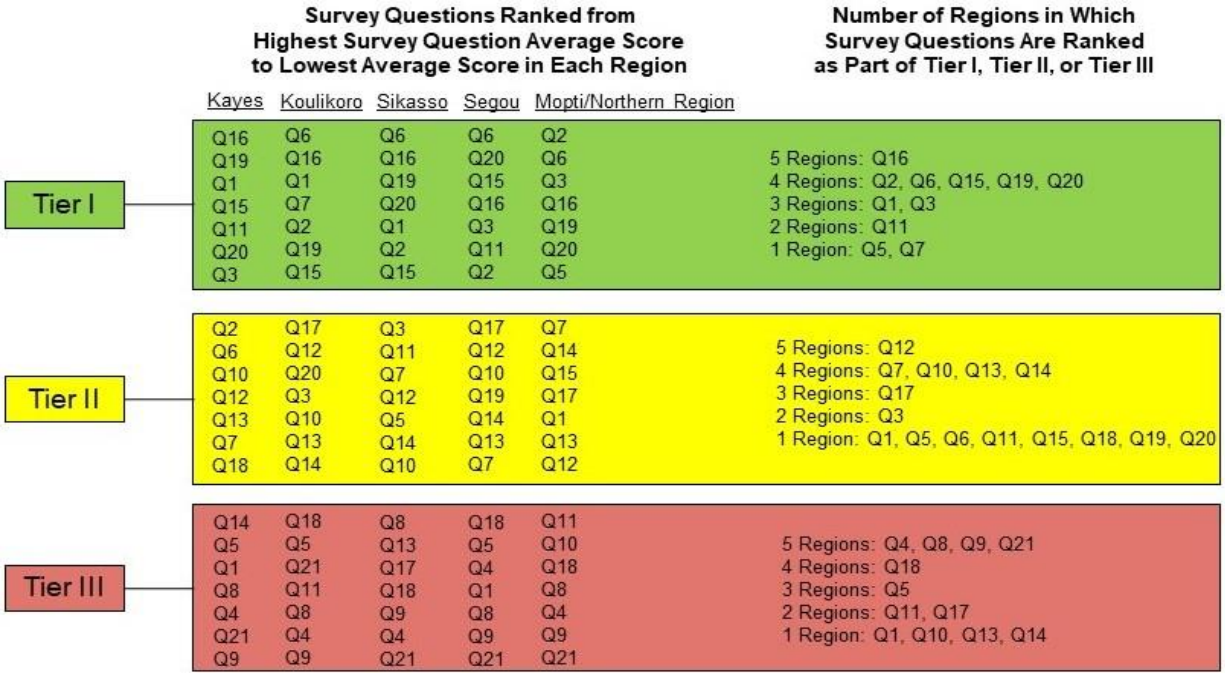

Figure 2: Survey Questions Divided into Three Tiers Based on Survey Question Average Rankings from Highest to Lowest.

Tier I: The seven highest-ranked Survey Question Average scores (ranked 1-7) in each region; Tier II: The seven middle-ranked Survey Question Average scores (ranked 8-14) in each region; Tier III: The seven lowest-ranked Survey Question Average Scores (ranked 15-21) in each region.

plausible given the terror threat and security situation in Mali over the last decade. While it appears that lab workers in Mali not only understand the importance of biosafety and biosecurity and are willing to implement good biosafety and biosecurity practices on an individual basis, the lab systems in which they work may not value biosafety and biosecurity to the same degree nor equip them with the necessary materials required to execute proper biosafety and biosecurity protocols. Q5, Q8, Q9 in Tier III of **Table 3** suggest that lab workers feel their employers prioritize results over proper lab safety measures and that biosafety and biosecurity violations and vulnerabilities are not rapidly mitigated.

Additionally, the lower-ranked Survey Question Average scores of Q4 and Q18 compared to other survey questions suggests that lab workers may lack the necessary training and personal protective equipment (PPE) they need to detect biosafety and biosecurity threats and properly protect themselves while working in their respective laboratories. Based on **Table 3**, lab workers may also believe that COVID-19 did not emerge naturally, which suggests they may believe it was accidental or deliberate in origin. This belief underscores the importance of fostering a strong culture of biosafety and biosecurity among lab workers because it presents an opportunity to leverage this sentiment into actions aimed at ensuring responsible conduct among laboratorians in the workplace in order to prevent accidental or deliberate biological incidents from occurring in the future. This belief also reinforces lab workers opinion on Q1 regarding the potential risk of bioterrorism or an attack with biological weapon.

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Table 3: Questions that were Ranked in Tier I and Tier III by Lab Workers from Three or More Regions.

Tier I*	**Tier III****
• Q1: There is a risk of bioterrorism or an attack with a biological weapon. • Q2: Controlling access to sensitive information is integral to biosecurity. • Q3: I understand the importance of trustworthiness determination. • Q6: I take professional pride in my work. • Q15: Risk assessments are important tools to identify areas of improvement and specific measures for reducing risk, including the level of containment required. • Q16. I believe that it is important to report not only laboratory accidents and incidents but also near misses. • Q19: Scientists have an obligation to do no harm. • Q20: I do/would/will report my concerns to the appropriate people, authorities, and/or agencies if I become aware of activities that violate the Biological and Toxin Convention, United Nations Security Council resolution 1540, or international customary law.	• Q4: My organization provides training on identifying symptoms of high-risk behavior in oneself and in others. • Q5: Biosafety and/or biosecurity deficiencies or vulnerabilities are corrected with a sense of urgency. • Q8: Biosafety and biosecurity infractions are handled appropriately. • Q9: My organization cares more about biosafety than about the results of our work. • Q18: I have adequate PPE available for me to perform my work safely and securely. • Q21: Covid-19 is a natural disease.

*Only questions from Tier I that appeared in the majority (three or more) of regions in Figure 2 are included in this list.

**Only questions from Tier III that appeared in the majority (three or more) of regions in Figure 2 are included in this list.

Opportunities

Given the above findings, the following opportunities exist to improve biosafety and biosecurity practices in Malian laboratories and may warrant further consideration.

Opportunity 1*:* *Encourage laboratory directors to prioritize biosafety and biosecurity practices over results.*

Strong leadership is vital to ensuring the success of a high containment laboratory and has a strong impact on what behaviors laboratory personnel adopt and prioritize. Implementation of this core recommendation will help to ensure the success of other recommendations and interventions. There should be clear and transparent processes for handling biosafety and biosecurity infractions and correcting vulnerabilities and deficiencies with a sense of urgency. Leadership should make this a priority by taking a formal approach to biorisk management, which could reduce laboratory acquired infections.

Opportunity 2: *Leverage lab workers understanding of, and apparent willingness to, implement biosafety and biosecurity practices*.

Malian lab workers understand the risks of working in high containment laboratories and the potentially far-reaching impact of those risks, as well as the importance of biosafety and biosecurity in mitigation. By building upon these fundamental beliefs and attitudes, principles for guiding decisions and behavior could be strengthened.

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Opportunity 3: *Increase access to protective equipment and supplies for lab workers in Mali.*

Access to PPE is essential to mitigating accidental exposure of lab workers to dangerous pathogens. Further investments by Mali and international partners is necessary to ensure lab workers have access to the PPE required to conduct their work in a safe and secure space.

Opportunity 4: *Implement continuous education and trainings.*

Implementing continuous biosafety and biosecurity education is vital to ensuring all lab workers are aware of proper biosafety and biosecurity protocols and are able to abide by appropriate biosafety and biosecurity measures while working. Also, offering biosafety and biosecurity trainings that enable staff to recognize vulnerabilities and suspicious behaviors will help lab workers recognize suspicious activities, identify potential vulnerabilities and misuse of biotechnologies, and increase their understanding about the repercussions of utilizing their expertise for nefarious purposes. Therefore, Malian stakeholders may wish to develop a training plan at the national and regional levels across multiple sectors, including agriculture, the environment, human health, and animal health.

LIMITATIONS

The exact number of laboratory workers in Mali is not well documented. According to the information provided by Mali's National Institute of Public Health via phone from the data manager at the SI-GRH (Human Resources Management Information System)—Mali's database for human resources, health, development, and family promotion—the official number of pharmacy laboratory technicians and Senior Health Technicians is 121 as of 2020. This number, though, is not representative of all lab workers in sectors outside of pharmacy. In 2014, the World Bank estimated that there were 350 laboratory workers in Mali [20]. Recognizing that these numbers are now likely outdated, the study population (n=94) represents over a quarter of that population of 350 as estimated by the World Bank and suggests our data may be useful for evaluating the beliefs, opinions, and attitudes of Malian laboratory workers. While there is no way to discern with a high degree of certainty that the study population is truly representative of all lab workers in Mali, this study does provide a useful baseline for evaluation of interventions moving forward.

Additionally, the use of zero as a potential answer makes some of the results difficult to interpret. Since a score of zero indicates that the question is either not applicable to the individual's work or that the individual does not know the answer, it is difficult to assess if a score of zero simply indicates whether a question was indeed not applicable or rather a lab worker did not have the personal knowledge or expertise to answer the question. Alternatively, there may have been instances where lab workers were close to scoring a question with a 1, 2, 3, 4, or 5 but chose zero as an option instead due to survey fatigue. Though values of zero were omitted from analysis, the results may have been different if zero was not an option in the survey. Furthermore, the basic knowledge level of all lab workers is not necessarily the same, which may have also influenced lab workers' answers to the 21 questions. Finally, this study addresses only one of the four elements in the IWG's Framework. Therefore it offers a partial picture of the culture of biosafety, biosecurity, and responsible conduct in the life sciences among Malian lab workers. Replicating this study with the Framework's survey questions addressing the other three elements (management systems; behavior of leadership and personnel; and principles for guiding decisions and behaviors) may be necessary to yield a clearer and more holistic picture of organizational culture of Malian laboratories.

CONCLUSION

Minimizing the risk of misuse and preventing the acquisition of equipment, expertise, and pathogenic material for illicit purposes requires an international approach and multisectoral synergy to promote international policies, guidance, and training. Weaknesses in either (or both) biosafety and biosecurity have been identified as one of the foremost root causes of laboratory-acquired infections, accidents, or near-misses. Consequently, establishing a strong biosafety and biosecurity culture is one of the fundamental risk management principles for an organization working

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with biological materials. Such a culture influences the attitudes, approaches, and commitment of individuals at all levels in the organization. The strength of an organizational culture of biosafety and biosecurity is grounded on how biosafety and biosecurity are perceived, valued, prioritized, and integrated.

Mali's current security situation and geopolitical environment highlight the importance of establishing a strong culture of biosafety and biosecurity practices. This study aims to assess beliefs, opinions, and attitudes of lab workers in order to better understand current sentiments towards biosafety and biosecurity and identify ways to encourage a stronger culture of biosafety, biosecurity, and responsible conduct in the life sciences. Future research can build upon the current study and assess the other three parts of the IWG's Framework to create a more complete picture of organizational culture among laboratories and lab workers in Mali.

This is the first report of an assessment of the culture of biosafety, biosecurity, and responsible conduct in the life sciences using the IWG's Framework. As such, it provides a model for international promotion surrounding the concept of a culture of responsible conduct in order to provide tailored international assistance to facilitate the development of action plans for gap mitigation and identify the required measures for a given country's laboratory or organization to further their biological risk management, best practices, and biological weapons non-proliferation goals.

ABBREVIATIONS

Africa CDC: Africa Centers for Disease Control and Prevention

BWC: Biological Weapons Convention

CSCOM: Community Health Centers

CSREF: Referral Health Centers

DURC: Dual Use Research of Concern

FESAP: Federal Experts Security Advisory Panel

G7GP: G7 Global Partnership Against the Spread of Weapons and Materials of Mass Destruction

GHSA: Global Health Security Agenda

IHR: International Health Regulations (2005)

IWG: International Working Group for Biosafety, Biosecurity, and Responsible Conduct in the Life Sciences

JEE: Joint External Evaluation

PPE: Personal Protective Equipment

SNL: Sandia National Laboratories

WHO: World Health Organization

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