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# Development of the Laboratory Biosafety Assessment Scale: Evidence from a Turkish Sample

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## Abstract

The present study aims to develop a valid and reliable scale to evaluate the effectiveness of biosafety applications in laboratory environments. The research resulted in a comprehensive four-dimensional scale, consisting of biosafety management and policies, personnel training and awareness, physical security and technical measures, and risk management and emergency preparedness. Each dimension represents the essential components of biosafety practices and reflects the systematic procedures required to maintain safe laboratory operations. In the scale development process, an extensive literature review was conducted to generate a detailed item pool, followed by content validation through expert evaluations to ensure theoretical and practical relevance. Exploratory and confirmatory factor analyses were then employed to examine the construct validity, and the results revealed that the four-dimensional model exhibited a statistically robust structure. Furthermore, the scale's reliability was supported by high internal consistency coefficients and satisfactory model fit indices. To assess its practical applicability, the scale was administered to personnel working in hospitals and research laboratories across Türkiye. The results demonstrated strong empirical support for the scale's reliability and validity. Overall, the developed scale serves as a useful instrument for measuring biosafety performance in laboratory settings and as a benchmark for organizations seeking to improve their biosafety management systems and policies.

**Keywords:** Biosafety Management and Policies, Personnel Training and Awareness, Physical Security and Technical Measures, Risk Management and Emergency Preparedness, Scale Development.

## Introduction

Biosafety refers to the set of measures and practices implemented to prevent biological and chemical agents from causing harm to human health, animals, and the environment (1). Laboratories operating in fields such as microbiology, chemistry, biotechnology, and genetic engineering inherently involve higher levels of risk due to their routine handling of hazardous microorganisms and toxic substances (2, 3). In the absence of adequate preventive measures, materials routinely used in laboratory settings may turn into serious threats through accidental exposure, laboratory-acquired infections, or environmental contamination (4). Therefore, biosafety practices are essential not only for protecting laboratory personnel but also for safeguarding public health and ecological systems (5).

Globally, laboratory biosafety practices are shaped by international standards and regulatory frameworks established by organizations such as the World Health Organization and the International Labour Organization, alongside national health authorities (6, 7). These frameworks define minimum biosafety requirements, containment principles, and risk mitigation strategies; however, their practical implementation varies considerably across laboratory types and institutional contexts (2). Laboratories engaged in microbiological research, genetic engineering, or biotechnological production require particularly strict containment and monitoring mechanisms to ensure the safe handling, storage, and disposal of biological materials (8).

In Türkiye, biosafety has gained increasing importance within both the healthcare system and scientific research environments (9, 10). The expansion of biotechnology, microbiology, and biomedical research activities has intensified attention toward laboratory safety standards; however, the quality and consistency of biosafety practices remain uneven across institutions (11, 12).



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Differences in laboratory capacity, infrastructure, administrative commitment, and regulatory enforcement contribute to variability in biosafety implementation. As a result, while some laboratories operate in close alignment with international standards, others face significant challenges in maintaining systematic and sustainable biosafety practices.

One of the central determinants of effective biosafety implementation is the presence of robust institutional management and clearly defined biosafety policies (13). Administrative commitment to regularly updating biosafety protocols, monitoring compliance, and enforcing standard operating procedures—particularly those related to waste management, sterilization, and material handling—plays a decisive role in ensuring laboratory safety (12, 14). The degree to which biosafety regulations are embedded into everyday laboratory operations reflects not only regulatory compliance but also the broader organizational culture surrounding safety practices (15).

Personnel training and awareness constitute another critical dimension of biosafety quality (16). Regular and structured training programs enable laboratory staff to recognize potential hazards, apply appropriate safety measures, and remain informed about updates in biosafety protocols (17). Orientation programs for newly employed personnel and continuous professional development activities further enhance biosafety awareness and contribute to a shared safety culture within laboratories (18, 19). Moreover, the timely communication of biosafety-related incidents and protocol changes strengthens institutional learning and reduces the likelihood of recurrent safety violations (20, 21).

In addition to administrative and human factors, physical security and technical infrastructure are fundamental components of laboratory biosafety (22, 23). The availability and proper use of personal protective equipment, the maintenance of biosafety cabinets and sterilization systems, and the secure storage and transportation of hazardous biological materials directly influence the effectiveness of biosafety practices (24, 25). Insufficient maintenance schedules or outdated technical infrastructure may compromise containment measures, thereby increasing risks to both personnel and the environment (26, 27).

Risk management and emergency preparedness further shape the overall quality of laboratory biosafety systems (28). Effective biosafety practices require systematic risk identification, the development of emergency response protocols, and regular drills to prepare personnel for unexpected incidents (29). Emergency simulations and continuous evaluation of risk management plans not only improve operational readiness but also support the long-term sustainability of biosafety policies within laboratory settings (25, 30).

Despite the growing emphasis on biosafety standards and regulatory frameworks, existing studies predominantly address biosafety practices in a descriptive or guideline-oriented manner. The absence of a standardized and empirically validated measurement instrument limits the systematic assessment and comparison of biosafety implementation quality across laboratory settings. Consequently, evidence-based monitoring, benchmarking, and improvement of biosafety practices remain constrained. Addressing this gap, the present study proposes a structured and empirically grounded framework for the systematic assessment of laboratory biosafety practices.

The present study aims to develop and validate a reliable measurement tool designed to assess the quality of biological safety practices in laboratory settings. The proposed scale addresses biological safety practices in four key dimensions: biosafety management and policies, personnel training and awareness, physical security and technical measures, and risk management and emergency preparedness. By operationalizing these dimensions within a unified measurement framework, the study presents a systematic and empirically based tool that supports the monitoring, benchmarking, and improvement of biological safety practices in various laboratory settings.

## Methodology

The development of the scale followed established methodological procedures to ensure validity and reliability (31, 32). In this context, a structured scale development framework was applied, beginning with a qualitative phase and followed by purification and data validation analyses (33).

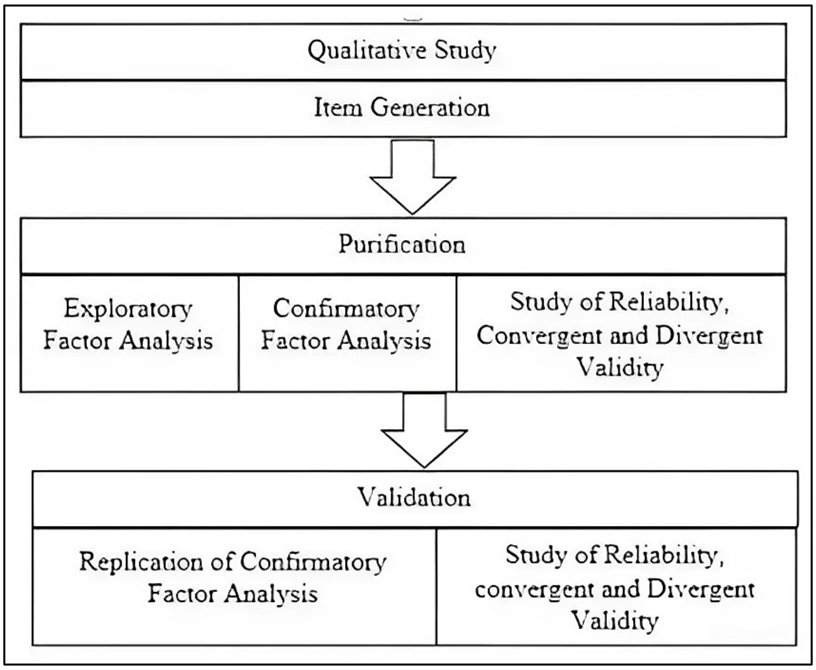


**Figure 1:** Scale Development Steps

Figure 1 presents the research scheme adopted for the scale development process. To generate the initial item pool, a structured review of the existing biosafety literature was conducted using relevant academic databases and guideline documents. Statements reflecting laboratory biosafety practices were systematically extracted and grouped according to thematic similarity. Overlapping or redundant expressions were merged, and ambiguous items were preliminarily refined prior to qualitative evaluation. The resulting preliminary item pool was then subjected to focus group discussions and linguistic review to improve clarity, content coverage, and contextual appropriateness before proceeding to the quantitative purification stage.

The qualitative inquiry based on existing literature and focus group discussions (FGD) was employed to inform the development of the Laboratory Biosafety Assessment Scale. Focus groups can be very effective as a preliminary design tool and can also be used to refine early drafts during the item development phase. For gathering additional information required for subsequent stages of technical scale development, focus group discussions are particularly useful (34).

# Results

## Focus Group Discussions (FGDs)

Two focus group discussions were conducted to support the qualitative phase of the scale development process. A total of 17 experts and academics participated in the focus group discussions, including hospital managers, physicians, laboratory managers and staff, academics, and linguists. Participants included laboratory managers, laboratory personnel, hospital administrators, and academicians with direct professional experience in laboratory biosafety practices, while linguists contributed specifically to the refinement and clarity of item wording during the scale development process. Participants were selected using a purposive sampling approach to ensure the inclusion of individuals with relevant professional experience in laboratory biosafety practices. Inclusion criteria required participants to have direct professional involvement in laboratory biosafety practices, while individuals without relevant experience were excluded. The discussions were conducted in two separate sessions, with nine participants in the first session and eight participants in the second. The participants represented a balanced gender distribution and ranged in age from 25 to 54 years. During the focus group discussions, participants were presented with scenario-based questions related to laboratory biosafety practices. Based on their professional experience and evaluation of the existing literature, participants shared their views on key biosafety issues. This exploratory phase enabled the identification of general items consistent with the existing literature. However, several statements were refined with the support of linguists to address issues related to length and ambiguity. As defining an appropriate content domain is a critical step in scale development, the focus group discussions contributed directly to the enhancement of content validity by clarifying and structuring the scale items.

In addition, insights derived from the focus group discussions directly informed specific revisions to item wording and supported the consolidation of conceptually overlapping statements. This qualitative input contributed to clearer alignment between individual items and their intended dimensions prior to the quantitative analyses.

To guide each focus group session in alignment with the objectives of the study, a structured set of questions was developed. Following thematic grouping, participants were provided with a questionnaire consisting of 16 items, prepared using a five-point Likert scale.

## Purification Study

The purification phase was conducted using data collected from managers and staff working in state and private hospitals, university hospitals, and state-owned and private laboratories located in the Turkish provinces of Istanbul, Ankara, Izmir, Bursa, Antalya, and Adana. A total of 642 participants were included in this phase, of whom 64.4% were male, and 23.2% were between the ages of 30 and 34. The sample consisted of laboratory managers and staff [50.9%], hospital managers [14.7%], and physicians [34.4%]. In terms of organizational tenure, 26.5% of the participants had worked in the same institution for 1–4 years, while 29.1% reported a tenure of 5–10 years.

Data were collected primarily through an online questionnaire administered over an approximately 4.5-month period (January–May 2025). Recruitment was conducted via institutional contacts across the specified hospitals and laboratories in the selected provinces, and participation was voluntary. Inclusion criteria were: (i) being currently employed in a laboratory-related role within the participating hospitals or laboratories in Istanbul, Ankara, Izmir, Bursa, Antalya, or Adana, (ii) being aged 18 years or older and (iii) providing informed consent. Exclusion criteria included: (i) not holding an active laboratory-related responsibility at the time of data collection and (ii) questionnaires that were incomplete to the extent that reliable scoring of the scale items was not possible.

Reliability analyses were conducted for the initial pool of 16 items, followed by an exploratory factor analysis (EFA) using principal axis factoring with varimax rotation. Eigenvalues were used as the criterion for determining the number of factors (35). The four-factor structure accounted for a substantial proportion of the total variance, with eigenvalues above the recommended threshold. The EFA results supported a four-factor solution. Based on the factor structure, the dimensions of the scale were identified as biosafety management and policies, personnel training and awareness, physical security and technical measures, and risk management and emergency preparedness.

**Table 1:** Exploratory Factor Analysis (EFA)

| Attributes | Mean Score | Standard Deviation | Factor Loadings | Reliability (Cronbach alpha) |
|---|---|---|---|---|
| **Factor 1: Biosafety Management and Policies** | | | | **0.78** |
| Laboratory-established biosafety procedures are updated regularly. | 3.04 | 1.26 | 0.65 | |
| Employee adherence to biosafety regulations is encouraged. | 3.42 | 1.13 | 0.71 | |
| Standard operating procedures for biological waste management and sterilization are followed. | 3.16 | 1.43 | 0.74 | |
| Biosafety regulations are successfully implemented by laboratory management. | 3.06 | 1.18 | 0.53 | |
| **Factor 2: Personnel Training and Awareness** | | | | **0.87** |
| Regular biosafety training is provided to laboratory staff. | 3.02 | 1.04 | 0.71 | |
| New hires go through a biosafety-focused orientation process. | 3.67 | 1.12 | 0.66 | |
| Workers are adequately informed about biosafety hazards and infractions. | 3.74 | 1.46 | 0.59 | |
| Advances in biosafety and changes to protocols are communicated to staff members. | 3.63 | 1.23 | 0.53 | |
| **Factor 3: Physical Security and Technical Measures** | | | | **0.74** |
| Adequate and efficient use of personal protective equipment (PPE) is provided. | 3.26 | 1.36 | 0.77 | |
| Regular inspections are conducted of sterilization equipment and biosafety cabinets. | 3.19 | 1.16 | 0.67 | |
| Safe storage and transportation are provided for biologically hazardous materials. | 3.24 | 1.18 | 0.61 | |
| Effective technical measures are put in place to improve biosafety in the laboratory setting. | 3.59 | 1.16 | 0.73 | |
| **Factor 4: Risk Management and Emergency Preparedness** | | | | **0.79** |

| | | | |
|---|---|---|---|
| Clearly defined protocols have been put in place for biosafety emergencies and violations. | 3.23 | 1.36 | 0.78 |
| To evaluate and lower biological risks, routine laboratory analyses are carried out. | 3.11 | 1.23 | 0.68 |
| Emergency drills are planned, and staff members participate in these exercises. | 3.06 | 1.33 | 0.82 |
| Biosafety measures are implemented in tandem with risk management policies. | 3.05 | 1.28 | 0.69 |

All factor loadings of the scale were found to be 0.50 or higher. Table 1 presents the reliability coefficients and factor loadings of the scale. Internal consistency reliability was assessed using Cronbach's alpha coefficients, and all scale dimensions exceeded the minimum acceptable threshold of 0.70, indicating satisfactory reliability (36). Convergent validity was also supported, as all standardized factor loadings obtained from the confirmatory factor analysis were greater than 0.70, as presented in Table 2 (37).

**Table 2:** Validity Estimates: Convergent Validity (Purification Stage)

| Constructs | Cronbach's alpha (Composite Reliability CR) | Average Variance Extracted (AVE) | Reliability | Convergent Validity |
|---|---|---|---|---|
| Biosafety Management and Policies | 0.78 | 0.62 | Yes | Yes |
| Personnel Training and Awareness | 0.87 | 0.57 | Yes | Yes |
| Physical Security and Technical Measures | 0.74 | 0.55 | Yes | Yes |
| Risk Management and Emergency Preparedness | 0.79 | 0.58 | Yes | Yes |

Discriminant validity of the scale was also established, as presented in Table 3. The off-diagonal elements of Table 3 report the correlations among the constructs (38). Discriminant validity was supported, given that the square root of the average variance extracted (AVE) for each construct exceeded the corresponding inter-construct correlations.

**Table 3:** Validity Estimates: Discriminant Validity (Purification Stage)

| Constructs | AVE | Biosafety Management and Policies | Personnel Training and Awareness | Physical Security and Technical Measures | Risk Management and Emergency Preparedness |
|---|---|---|---|---|---|
| Biosafety Management and Policies | 0.62 | 0.75 | | | |
| Personnel Training and Awareness | 0.57 | 0.52 | 0.74 | | |
| Physical Security and Technical Measures | 0.55 | 0.33 | 0.30 | 0.76 | |
| Risk Management and Emergency Preparedness | 0.58 | 0.23 | 0.12 | 0.23 | 0.72 |

Note: Diagonal elements (in bold) are the square root of the average variance explained (AVE).

The measurement model, comprising 16 items developed during the item generation phase, demonstrated an acceptable fit to the data. As presented in Table 4, all model fit indices met the recommended threshold values reported in prior methodological studies (39). Based on these results, the scale was finalized using the values reported in Table 5 and was deemed suitable for further use. The final version of the developed scale is presented in Table 5. In addition, Table 5 reports the key sources that contributed substantially to the development of each item included in the scale.

**Table 4:** Model Fit Indices (Purification Stage)

| Indices | Recommended Value | References | Model Fit Indices |
|---|---|---|---|
| GFI | ≥0.90 | (39, 40) | 0.93 |
| CFI | ≥0.93 | (39-42) | 0.98 |
| CMIN/df | <3 | (39) | 1.62 |
| AGFI | ≥0.80 | (39, 40) | 0.84 |
| RMSEA | ≤0.08 | (39, 40, 43) | 0.06 |
| NFI | ≥0.90 | (41, 42, 44) | 0.92 |
| NNFI (TLI) | ≥0.90 | (44) | 0.94 |
| SRMR | <0.08 | (44) | 0.07 |

Note: GFI, CFI, CMIN/df, AGFI, RMSEA, NFI, NNFI, SRMR are as per recommended value.

**Table 5:** Proposed Laboratory Biosafety Assessment Scale

| Attributes | References |
|---|---|
| **Factor 1: Biosafety Management and Policies** | |
| Laboratory-established biosafety procedures are updated regularly. | (12, 13) |
| Employee adherence to biosafety regulations is encouraged. | (13, 14) |
| Standard operating procedures for biological waste management and sterilization are followed. | (13, 14) |
| Biosafety regulations are successfully implemented by laboratory management. | (12, 14, 15) |
| **Factor 2: Personnel Training and Awareness** | |
| Regular biosafety training is provided to laboratory staff. | (16-18) |
| New hires go through a biosafety-focused orientation process. | (18, 19) |
| Workers are adequately informed about biosafety hazards and infractions. | (19-21) |
| Advances in biosafety and changes to protocols are communicated to staff members. | (19, 21) |
| **Factor 3: Physical Security and Technical Measures** | |
| Adequate and efficient use of personal protective equipment (PPE) is provided. | (22, 23) |
| Regular inspections are conducted of sterilization equipment and biosafety cabinets. | (22, 24, 25) |
| Safe storage and transportation are provided for biologically hazardous materials. | (25, 26) |
| Effective technical measures are put in place to improve biosafety in the laboratory setting. | (25, 27) |
| **Factor 4: Risk Management and Emergency Preparedness** | |
| Clearly defined protocols have been put in place for biosafety emergencies and violations. | (13, 25) |
| To evaluate and lower biological risks, routine laboratory analyses are carried out. | (13, 28) |
| Emergency drills are planned, and staff members participate in these exercises. | (28, 29) |
| Biosafety measures are implemented in tandem with risk management policies. | (13, 28, 29) |

## Data Validation

The same analytical procedure was applied to validate the scale using confirmatory factor analysis on an independent sample of 524 participants. This validation sample was collected using the same recruitment approach, primarily via an online questionnaire distributed through institutional contacts, and participation was voluntary. The same inclusion and exclusion criteria were applied to ensure comparability between the purification and validation phases. Of this sample, 60.1% were male, 21.4% were between the ages of 30 and 34, and 46.4% were laboratory managers and staff. In terms of organizational tenure, 41.8% of the participants reported working in the same position for 5–10 years. A comparison of factor loadings obtained from the purification and validation phases is presented in Table 6.

**Table 6:** Factor Loadings for Purification and Validation Stages

| Constructs | Purification | Validation |
|---|---|---|
| Laboratory-established biosafety procedures are updated regularly. | 0.65 | 0.82 |
| Employee adherence to biosafety regulations is encouraged. | 0.71 | 0.84 |
| Standard operating procedures for biological waste management and sterilization are followed. | 0.74 | 0.62 |
| Biosafety regulations are successfully implemented by laboratory management. | 0.53 | 0.65 |
| Regular biosafety training is provided to laboratory staff. | 0.71 | 0.57 |
| New hires go through a biosafety-focused orientation process. | 0.66 | 0.73 |
| Workers are adequately informed about biosafety hazards and infractions. | 0.59 | 0.84 |
| Advances in biosafety and changes to protocols are communicated to staff members. | 0.53 | 0.55 |
| Adequate and efficient use of personal protective equipment (PPE) is provided. | 0.77 | 0.61 |
| Regular inspections are conducted of sterilization equipment and biosafety cabinets. | 0.67 | 0.74 |
| Safe storage and transportation are provided for biologically hazardous materials. | 0.61 | 0.73 |
| Effective technical measures are put in place to improve biosafety in the laboratory setting. | 0.73 | 0.71 |
| Clearly defined protocols have been put in place for biosafety emergencies and violations. | 0.78 | 0.72 |
| To evaluate and lower biological risks, routine laboratory analyses are carried out. | 0.68 | 0.56 |
| Emergency drills are planned, and staff members participate in these exercises. | 0.82 | 0.83 |
| Biosafety measures are implemented in tandem with risk management policies. | 0.69 | 0.70 |

Internal consistency reliability of the scale was supported by Cronbach's alpha coefficients. As reported in Table 7, the coefficients for the scale dimensions were 0.81, 0.84, 0.71 and 0.73, all exceeding the acceptable threshold. In addition, the average variance extracted (AVE) values were above 0.50, indicating adequate convergent validity.

**Table 7:** Validity Estimates: Convergent Validity (Validation Stage)

| Constructs | Cronbach's alpha (Composite Reliability CR) | Average Variance Extracted (AVE) | Reliability | Convergent Validity |
|---|---|---|---|---|
| Biosafety Management and Policies | 0.81 | 0.55 | Yes | Yes |
| Personnel Training and Awareness | 0.84 | 0.58 | Yes | Yes |
| Physical Security and Technical Measures | 0.71 | 0.52 | Yes | Yes |
| Risk Management and Emergency Preparedness | 0.73 | 0.61 | Yes | Yes |

**Table 8:** Validity Estimates: Discriminant Validity (Validation Stage)

| Constructs | AVE | Biosafety Management and Policies | Personnel Training and Awareness | Physical Security and Technical Measures | Risk Management and Emergency Preparedness |
|---|---|---|---|---|---|
| Biosafety Management and Policies | 0.55 | 0.77 | | | |
| Personnel Training and Awareness | 0.58 | 0.49 | 0.72 | | |
| Physical Security and Technical Measures | 0.52 | 0.31 | 0.33 | 0.75 | |
| Risk Management and Emergency Preparedness | 0.61 | 0.24 | 0.15 | 0.21 | 0.74 |

An examination of discriminant validity results indicated that the values reported on the diagonal exceeded the corresponding inter-construct correlations within each column. These findings support the discriminant validity of the scale, as presented in Table 8.

Discriminant validity of the scale was further supported, as presented in Table 8. In addition, consistent with the purification phase, the confirmatory factor analysis results indicated that the four-factor measurement model demonstrated an adequate fit to the data. As reported in Table 9, all model fit indices—including CFI [0.94], GFI [0.92], CMIN/df [1.95], AGFI [0.86], RMSEA [0.07], NFI [0.92], NNFI [0.91], and SRMR [0.05]—were within the recommended threshold values

**Table 9:** Model Fit Indices (Validation Stage)

| Indices | Recommended Value | Model Fit Indices |
|---|---|---|
| GFI | ≥0.90 | 0.92 |
| CFI | ≥0.93 | 0.94 |
| CMIN/df | <3 | 1.95 |
| AGFI | ≥0.80 | 0.86 |
| RMSEA | ≤0.08 | 0.07 |
| NFI | ≥0.90 | 0.92 |
| NNFI (TLI) | ≥0.90 | 0.91 |
| SRMR | <0.08 | 0.05 |

# Discussion

Laboratory biosafety practices in Türkiye have shown notable improvement in recent years, particularly following the COVID-19 pandemic (45). Nevertheless, regional disparities and inconsistencies in the implementation of institutional biosafety standards remain evident (46). While university hospitals, state hospitals, and several private healthcare institutions—especially those located in metropolitan areas—have made substantial progress in aligning biosafety protocols with international standards, smaller-scale laboratories and certain public research centers continue to experience limitations in the consistency and sustainability of biosafety practices (47).

From the perspective of laboratory management and institutional policies, larger organizations tend to exhibit clearly defined biosafety strategies, regularly updated protocols, and established audit mechanisms (46). In such settings, managerial support has facilitated the development of a biosafety-oriented organizational culture, with waste management and sterilization processes being implemented in accordance with standardized procedures (10). In contrast, resource-constrained laboratories may experience disruptions in update and audit processes, increasing the likelihood that potential biosafety risks are insufficiently monitored or addressed (48).

Regarding personnel training and awareness, the emphasis placed on biosafety training across Türkiye has increased in the post-pandemic period (10). Large institutions commonly provide structured training programs and orientation processes; however, some laboratories lack continuous and up-to-date training materials, as well as consistent employee participation in training activities (47). The systematic implementation of training and awareness initiatives is essential for enabling personnel to accurately identify biosafety risks and report potential hazards at an early stage (49). Consequently, variations in training practices constitute a significant source of inconsistency in biosafety implementation across institutions (50).

In terms of physical security and technical measures, laboratories equipped with modern infrastructure are generally able to perform regular maintenance and monitoring of personal protective equipment, biosafety cabinets, and sterilization systems (12). Conversely, insufficient infrastructural investment in some institutions may result in delays or inadequacies in maintenance schedules, thereby reducing the effectiveness of safety measures during critical operations (51). Such deficiencies, particularly in laboratories handling high-risk biological materials, may pose substantial risks to both personnel and the surrounding environment (14).

With respect to risk management and emergency preparedness, established protocols and drill practices in Türkiye tend to be implemented more systematically within larger institutions (52). Regular emergency drills contribute to organizational preparedness for unexpected incidents (53). However, in certain laboratory settings, risk assessment processes may remain incomplete, emergency plans may not be regularly updated, and employee awareness may be limited. These shortcomings can adversely affect overall laboratory biosafety performance (52).

Overall, while biosafety practices in well-resourced laboratories located in major urban centers are generally comparable to international standards, smaller laboratories and those operating in rural regions have yet to reach similar levels of consistency and quality. This disparity highlights the need for targeted infrastructure investments and centralized monitoring mechanisms to promote a more uniform biosafety culture nationwide. The establishment of national standards and the consistent enforcement of biosafety practices across institutions are therefore critical to strengthening laboratory biosafety systems in Türkiye.

## Conclusion

The scale developed in this study provides a comprehensive assessment of biosafety practices in laboratory environments by capturing management and institutional policies, personnel training and awareness, physical security and technical measures, and risk management and emergency preparedness. Evidence from the Turkish context indicates that while biosafety practices in larger and well-resourced institutions are largely aligned with international standards, notable deficiencies persist in certain laboratories, particularly those with limited resources. These findings underscore the need for targeted infrastructure investments and the implementation of centralized audit and monitoring mechanisms, particularly in resource-constrained laboratories. A key strength of the study lies in the use of large and independent samples in both the purification [n = 642] and validation [n = 524] phases, which enhances the robustness, generalisability, and empirical validity of the proposed scale.

The application of the scale enables the systematic identification of strengths and weaknesses in laboratory biosafety practices, thereby supporting institutions in the development of targeted improvement strategies. In addition, the scale offers empirical evidence that can inform revisions of biosafety policies at the national level. The results further emphasize that effective biosafety practices are essential not only for individual laboratory performance but also for the protection of public health and environmental safety. Accordingly, policymakers and laboratory managers should prioritize sustained investments in infrastructure and risk management systems, supported by consistent implementation of national standards.

Despite these contributions, several limitations should be acknowledged. First, the study was conducted within a specific national context, which may limit the generalizability of the findings to different institutional or regulatory environments. Second, the cross-sectional and self-reported nature of the data may introduce common method bias despite procedural precautions. Future research may validate the scale across different countries, laboratory types, and regulatory settings, and may also employ longitudinal designs to further examine the temporal stability and predictive validity of the proposed measurement framework. Such efforts would contribute to the cumulative refinement and broader applicability of the Laboratory Biosafety Assessment Scale.

This study was conducted in full compliance with established research ethics principles. All participants were informed about the purpose of the research and assured of the confidentiality and scientific use of their responses. The author declares no conflict of interest and confirms that no financial or institutional support was received during the conduct of the study. No artificial intelligence–assisted technologies were used in the preparation of this manuscript. The study was carried out as an independent, single-authored

work, and the data supporting the findings are available from the author upon reasonable request.

## Abbreviations

AVE: Average Variance Extracted, CFA: Confirmatory Factor Analysis, CFI: Comparative Fit Index, CR: Composite Reliability, EFA: Exploratory Factor Analysis, GFI: Goodness-of-Fit Index, NFI: Normed Fit Index, RMSEA: Root Mean Square Error of Approximation, SRMR: Standardized Root Mean Square Residual.

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## Author Contributions

Bora Coşar: conceptualization, methodology, data collection, formal analysis, manuscript preparation.

## Conflict of Interest

The author declares that there are no conflicts of interest related to this research work. No financial, personal, or professional relationships have influenced the findings, analysis, or conclusions presented in this study.

## Data Availability

The data supporting the findings of this study are available from the author upon reasonable request.

## Declaration of generative AI and AI assisted technologies in the writing process

The author declares no use of Artificial Intelligence AI for the write-up of this manuscript.

## Ethics Approval

This study was conducted in accordance with the ethical guidelines and principles.

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