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RISK DETERMINANTS AND MITIGATION STRATEGIES IN LABORATORY ENVIRONMENTS: A SYSTEMATIC REVIEW OF OCCUPATIONAL INCIDENTS AMONG UNIVERSITY STUDENTS

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ABSTRACT

Background: Occupational incidents in academic laboratories pose a significant threat to student health and safety. This systematic review identifies and synthesizes the evidence on key risk determinants and corresponding mitigation strategies. **Method**: Conducted in accordance with PRISMA 2020 guidelines, the review systematically searched PubMed and Scopus for primary studies (2019–2024), followed by a rigorous process of study selection, data extraction, and quality appraisal using Joanna Briggs Institute (JBI) tools. **Result**: From 23 included studies, this review identified 22 key risk determinants, most prominently a pervasive lack of safety compliance, insufficient training, and a weak organizational safety culture. These foundational issues were compounded by specific chemical, microbial, and ergonomic hazards. The methodological quality of the evidence base was varied, with a predominance of cross-sectional designs carrying a moderate risk of bias. The review found that effective mitigation strategies were consistently multi-component and systemic, integrating enhanced training, strict adherence to Standard Operating Procedures (SOPs), consistent PPE utilization, and visible safety leadership. **Conclusion**: This synthesis demonstrates that laboratory safety is not a passive state but the outcome of a holistic, proactive framework. To build a higher-quality evidence base, future research must prioritize robust designs, such as longitudinal and intervention studies, to establish causality and evaluate the long-term effectiveness of safety programs.

Keywords: Laboratory Safety, Systematic Review, Occupational Health, Risk Assessment, University Students

INTRODUCTION

The increasing incidence of occupational accidents among students in academic laboratories has become a significant concern. This phenomenon is attributed to several factors, including negligence (Cook-Shimanek et al., 2020), hazardous laboratory environments (Keckler et al., 2019), and an insufficient understanding of safety protocols

(Bujang et al., 2023). These circumstances not only pose acute threats to student health but also compromise the integrity of the educational atmosphere. Maintaining a safe laboratory environment is paramount, as it directly impacts student well-being and the quality of their practical learning experiences (Marin et al., 2019). Therefore, further research is necessary to comprehensively identify the primary risk factors and to investigate effective mitigation strategies for enhancing safety in diverse academic laboratory settings.

This study aims to identify the specific factors that elevate the risk of occupational accidents for students in academic laboratories. It seeks to elucidate the primary drivers impacting laboratory safety and to evaluate the efficacy of various mitigation strategies implemented to reduce incident rates. By doing so, this research provides actionable recommendations for enhancing safety protocols within these environments. The main research questions are: (1) What are the principal factors contributing to the risk of occupational accidents among students in academic labs? and (2) Which mitigation techniques have proven most effective in reducing these risks? Ultimately, addressing these questions will contribute to the development of a safer learning environment by improving the collective understanding of inherent hazards and optimal safety practices.

METHOD

This systematic literature review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021). It is noted that the review protocol was not preregistered.

Eligibility Criteria

To ensure the relevance and focus of the review, eligibility criteria were defined based on the Population, Intervention, Comparison, and Outcome (PICO) framework. The population (P) of interest comprised university students, both undergraduate and postgraduate, within academic laboratory settings; studies that also included staff were considered if student-specific data were available for distinct analysis. The intervention or exposure (I) encompassed any study that identified or analyzed risk determinants (e.g., chemical exposure, unsafe practices) or evaluated mitigation strategies (e.g., safety training, PPE utilization). The comparison (C) criteria were intentionally flexible to accommodate various study designs, including those with control groups, pre-post assessments, or descriptive studies that provided relevant data. Finally, the outcomes (O) of interest were comprehensive, including the identification of risk determinants, the incidence of occupational incidents, the effectiveness of mitigation strategies, and observable changes in safety behavior and culture.

Additional Inclusion and Exclusion Criteria:

Beyond the PICO framework, the selection process was further refined by several inclusion and exclusion criteria. This review was restricted to primary empirical research, including observational studies and experimental trials, while systematically excluding literature reviews, meta-analyses, and editorials. The search was limited to articles published in the English language between January 1, 2019, and December 31, 2024. The designated setting was academic laboratories. The scope was intentionally broad to encompass various relevant laboratory types (e.g., chemical, biomedical, food processing) to ensure a sufficient evidence base. Finally, accessibility was a key criterion; only articles for which the full text was available were included in the final synthesis.

Information Sources and Search Strategy

A systematic search of relevant literature was performed across two electronic databases: PubMed and Scopus. The database search was conducted in February 2025. This primary search was supplemented by a manual screening of the reference lists of all included articles, a technique known as "snowballing," to identify any studies not captured by the initial search.

The search strategy was constructed by combining three core concepts with Boolean operators (AND, OR): (1) population, (2) exposure/environment, and (3) outcomes. For the population concept, keywords included *"students"*[MeSH], "student*", and "undergraduate*". For the exposure/environment concept, terms included *"laboratories"*[MeSH], "laboratory", and "lab". For the outcome concept, a broad range of terms was utilized, including *"occupational health"*[MeSH], *"safety"*[MeSH], "safety", "risk*", "hazard*", and "incident*". This comprehensive strategy was designed to capture a wide spectrum of studies related to safety incidents and risk factors. The full search string, adapted for the specific syntax of each database, is available as supplementary material

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Study Selection, Data Extraction, and Quality Appraisal

Study Selection

All records identified from the database searches were imported into a reference management software (e.g., Zotero/Mendeley), and duplicates were removed. The selection process was conducted in two stages. First, two reviewers (T.S.P. and B.W.) independently screened the titles and abstracts of all unique records against the predefined eligibility criteria. Second, the full texts of potentially relevant articles were retrieved and assessed for final inclusion by the same two reviewers. Any disagreements at either stage were resolved through discussion or, if necessary, by consulting a third reviewer (D.L.) to reach a consensus. The entire selection process is documented in the PRISMA flow diagram (Figure 1).

Data Extraction

Following the database searches, all identified records were imported into reference management software (e.g., Zotero, Mendeley) for the removal of duplicates. The study selection was then conducted in a two-stage process. In the first stage, two reviewers (T.S.P. and B.W.) independently screened the titles and abstracts of all unique records against the predefined eligibility criteria. In the second stage, the same two reviewers retrieved and assessed the full texts of potentially relevant articles for final inclusion. Throughout both stages, any disagreements were resolved through discussion to reach a consensus. A third reviewer (D.L.) was consulted to arbitrate any unresolved discrepancies. The entire selection process is visually documented in the PRISMA flow diagram (see Figure 1).

Quality Appraisal

The methodological quality and risk of bias of each included study were independently evaluated by two reviewers (T.S.P. and Y.S.). This assessment utilized the

Joanna Briggs Institute (JBI) Critical Appraisal Tools, which offer specific checklists tailored to the various study designs present in this review (e.g., cross-sectional, case-control, case reports). For each item on the checklist, reviewers assigned a response of "yes," "no," "unclear," or "not applicable." Based on the percentage of criteria met, studies were categorized as having a "low" (>70%), "moderate" (50-70%), or "high" (<50%) risk of bias. It is important to note that no studies were excluded based on their quality score; rather, the results of the appraisal were used to inform the synthesis and interpretation of the findings.

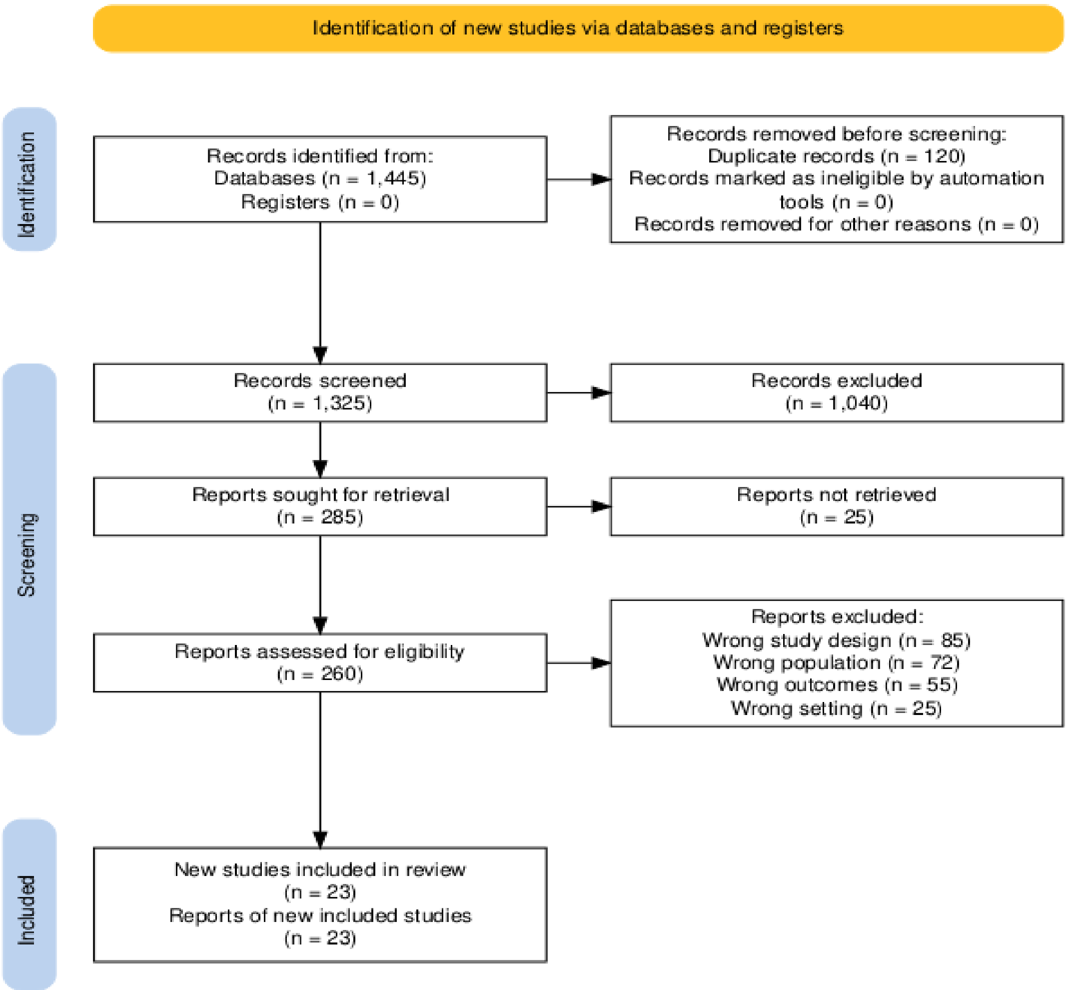

Figure 1 Prisma Screening Results

RESULT

The systematic literature review yielded insights into diverse aspects of safety, risk factors, and mitigation measures across various academic laboratory settings. For example, Salazar-Escoboza et al. (2020) investigated the safety climate perceived by students in academic laboratories, revealing a moderate safety perception and underscoring the importance of role modeling by staff to foster safety awareness. In a similar vein, Pertiwi et al. (2021) identified high-risk activities within a material laboratory and proposed specific controls to mitigate hazard exposure. Collectively, the reviewed studies highlight recurring themes of inadequate compliance, insufficient training, and inconsistent safety practices across different laboratory environments.

Specific examples from food-related and other laboratory contexts demonstrated notable efficacy. For instance, a randomized controlled trial by Orou Seko et al. (2022) aimed at improving practices in dibiteries resulted in reduced microbial contamination and heightened hygiene awareness among food handlers. This finding underscores the importance of targeted interventions. Similarly, an investigation into a foodborne disease outbreak at a Malaysian boarding school by Bujang et al. (2023) identified a significant association between specific dishes and the subsequent illness, thereby highlighting the critical need for effective food safety management in institutional settings.

The review also identified several studies investigating specific individual safety incidents. Davidi et al. (2021), for example, documented contamination issues in COVID-19 surveillance tests, leading to recommendations for stricter laboratory protocols. In another case, Qingmei Tian et al. (2022) reported on a rabbit-derived eye infection in a medical student, proposing mitigation measures that included enhanced testing protocols and specific clinical interventions. Furthermore, Cook-Shimanek et al. (2020) detailed a case of allergic contact dermatitis in a student resulting from chemical exposure, which underscored the critical importance of appropriate Personal Protective Equipment (PPE) and adherence to safety protocols.

The importance of establishing robust occupational health and safety (OHS) standards in specialized environments was a recurring theme. For instance, studies by Davidson et al. (2018) in cannabis production and AlShammari et al. (2021) in biomedical labs both advocated for the implementation of clear standards and frequent inspections to effectively manage risks. Complementing this, other research highlighted the value of proactive safety assessment tools. Willey et al. (2019) and Marin et al. (2019) demonstrated the utility of instruments like the Chemistry Laboratory Safety Climate Survey (CLASS) for identifying safety gaps and enhancing students' hazard awareness.

In food-related contexts, maintaining strict hygiene and quality control was paramount. Compaore et al. (2022) evaluated the microbiological quality of street foods, while Rito et al. (2020) assessed salt reduction strategies in school meals; both studies concluded that rigorous control measures were essential. Similarly, Chen et al. (2019) analyzed a foodborne outbreak and identified effective countermeasures, including the isolation of contamination sources and enhanced hygiene among food handlers. A comprehensive summary of the characteristics of all included studies is detailed in Table 1.

Table 1. Characteristics of Included Studies

ID	Author(s) & Year	Study Design	Quality Appraisal	Population & Sample Size	Risk Determinants	Mitigation Measures
1	Salazar-Escoboza et al., 2020	Cross-sectional survey	Moderate Risk	438 students, three Mexican universities	Inadequate safety compliance, limited training, equipment/substance risks	Enhanced training, emphasis on safety leadership

ID	Author(s) & Year	Study Design	Quality Appraisal	Population & Sample Size	Risk Determinants	Mitigation Measures
2	Pertiwi et al., 2021	Observational cross-sectional	Moderate Risk	Material lab at Bali State Polytechnic	High chemical risks, noise/dust hazards, lack of PPE	Regular PPE enforcement, OSH training, improved testing protocols
3	Orou Seko et al., 2022	Randomized Controlled Trial (RCT)	Low Risk	40 dibiteries in Dakar, Senegal	High microbial contamination, poor hygiene, inconsistent cold chain	Hygiene training, provision of hygiene kits, monitoring
4	Bujang et al., 2023	Case-control study	Moderate Risk	597 female students (13-17 years)	*Bacillus cereus* contamination, poor temperature monitoring, inadequate hygiene	Suspension of canteen, educational talks on food safety
5	Davidi et al., 2021	Observational study	Moderate Risk	300 cases from five research universities	Amplicon contamination in labs, difficulty distinguishing true positives	Follow-up testing with multiple targets, stricter lab protocols for DNA
6	Tian et al., 2022	Case report	High Risk	19-year-old medical student in China	Contact with rabbit hair, lack of hand hygiene	Removal of worms, use of ophthalmic drops
7	Cook-Shimanek et al., 2020	Case report	High Risk	1 undergraduate student (19-year-old)	Exposure to sensitizing chemicals, inadequate PPE and training	Implementation of safety protocols, provision of PPE, clearing fume hoods
8	Kołcz et al., 2020	Prospective observational study	Moderate Risk	37 nurses in Poland	Musculoskeletal pain, non-compliance with ergonomic practices, stress	Training on ergonomic principles, body composition monitoring

ID	Author(s) & Year	Study Design	Quality Appraisal	Population & Sample Size	Risk Determinants	Mitigation Measures
9	Davidson et al., 2018	Literature review (descriptive synthesis)	High Risk	Workers in Australian cannabis industry	Exposure to organic dust, psychoactive substances, allergens	Use of PPE (respirators, gloves), adoption of interim exposure standards.
10	Wang et al., 2019	Randomized cross-over trial	Low Risk	16 adults with traumatic brain injury (TBI)	Cognitive impairments affecting task sequencing, need for external assistance	Context-aware automatic prompting system (Visual Impact Pro)
11	Marin et al., 2019	Cross-sectional survey	Moderate Risk	306 & 357 students (two studies)	Inconsistent safety culture, lack of proactive safety	Use of Safety Climate Survey (CLASS) for college settings
12	Willey et al., 2020	Experiential learning-based study	Moderate Risk	Chemical engineering students	Limited exposure to hazard analysis, lack of real-world experience	Use of checklist, Bowtie, HAZOP analysis, industrial mentorship
13	Ayi & Hon, 2019	Cross-sectional survey	Moderate Risk	56 participants at a Canadian university	Inconsistent safety practices, limited PPE compliance, low risk assessment awareness	Training enhancements, increased safety monitoring
14	Keckler et al., 2019	Continuous Quality Improvement (CQI) cycle	Low Risk	Public health lab staff in the U.S. CDC	Lack of risk awareness, inconsistent use of engineering controls	Development of annual safety survey, introduction of 3D risk assessment
15	Hasan & Younos, 2020	Cross-sectional survey	Moderate Risk	964 students from Dhaka	Underreporting of near-misses, low safety awareness,	Targeted safety training,

ID	Author(s) & Year	Study Design	Quality Appraisal	Population & Sample Size	Risk Determinants	Mitigation Measures
				University, Bangladesh	higher risk attitudes in males	emphasis on student education in safety practices
16	Abu-Siniyeh & Al-Shehri, 2021	Cross-sectional survey	Moderate Risk	185 participants (142 students, 43 workers)	Poor awareness of extinguisher use, insufficient knowledge of hazards	Enhanced fire training, safety signage, emphasis on emergency preparedness
17	Salazar-Escoboza et al., 2020	Cross-sectional survey	Moderate Risk	438 students in Northwest Mexico	Inadequate compliance with safety regulations, poor attitudes towards safety	Emphasis on safety training, strengthening safety attitudes among staff
18	Alshammari et al., 2021	Cross-sectional, prospective study	Moderate Risk	Staff and students in 2 biomedical labs, Qatar University	High percentage of chemical/ergonomic hazards, prevalent biohazard risks	Control measures with PPE, implementing SOPs, frequent safety inspections
19	Dehdashti et al., 2020	Cross-sectional study	Moderate Risk	38 sites within an academic setting (Iran)	High-risk areas in labs (chemical, ergonomic, fire, electrical hazards)	Risk reduction training, implementation of HSE guidelines
20	Bujang et al., 2023	Outbreak investigation report	Moderate Risk	597 students in a boarding school, Malaysia	Cross-contamination, inadequate temperature monitoring, poor hygiene	Suspension of canteen, food handler education, temperature monitoring
21	Rito et al., 2020	Intervention-based study	Moderate Risk	5,773 students (3-21 years) in 25 schools	High sodium intake in school meals, cultural	Development of new school menus,

ID	Author(s) & Year	Study Design	Quality Appraisal	Population & Sample Size	Risk Determinants	Mitigation Measures
					preference for salty foods	training for food handlers
22	Compaore et al., 2022	Descriptive, cross-sectional study	Moderate Risk	101 food samples from five cities in Burkina Faso	Poor hygiene, high bacterial loads in rice and milk samples	Vendor training in hygiene, regular quality checks
23	Chen et al., 2019	Retrospective cohort study	Moderate Risk	209 students in Shunyi District, Beijing	Norovirus and *Bacillus cereus* contamination from high-risk food stalls	Isolation of cases, closure of high-risk stalls, disinfection of environment

Risk Determinants

The reviewed literature reveals a complex and multifaceted landscape of risk factors associated with occupational incidents among students in laboratory settings. These determinants range from individual behaviors, such as inadequate adherence to safety procedures and inconsistent use of Personal Protective Equipment (PPE), to systemic issues like insufficient training programs and a lack of safety leadership. This review synthesized numerous significant risk factors, including chemical exposure, ergonomic hazards, microbiological contamination, and poor hygiene practices. Understanding these determinants is essential for developing targeted interventions designed to enhance safety protocols, reduce incident rates, and ultimately foster a safer laboratory environment for students.

While this review was initially designed to focus specifically on risk determinants and mitigation strategies within food processing laboratories, the limited availability of research necessitated an expansion of scope. Consequently, the review was broadened to include analogous laboratory environments, such as chemical and biomedical labs, to construct a more comprehensive evidence base. This expanded approach resulted in the identification of 22 key risk determinants across a diverse spectrum of laboratory settings.

Among the 22 determinants, inadequate safety compliance and limited safety awareness emerged as the most prominent. Deficient compliance with safety regulations, compounded by inconsistent safety practices, was a recurrent issue across both academic and research settings (Salazar-Escoboza et al., 2020; Ayi & Hon, 2018). This was often linked to poor awareness of specific safety procedures, such as proper fire extinguisher use, and a general lack of proactive safety initiatives (Abu-Siniyeh & Al-Shehri, 2021; Marin et al., 2019). Furthermore, limited training was identified as another recurring determinant; insufficient safety education demonstrably impaired the ability of laboratory users to recognize and effectively mitigate hazards (Salazar-Escoboza et al., 2020; Cook-Shimanek et al., 2020; Willey et al., 2019).

Chemical hazards constituted another significant category of risk, particularly in settings where high-risk substances were handled without adequate safety measures (Pertiwi et al., 2021; Cook-Shimanek et al., 2020; AlShammari et al., 2021). Closely related to this was the insufficient use of Personal Protective Equipment (PPE). The review found that inconsistent or inadequate PPE utilization was a critical determinant that significantly heightened the risk of exposure to chemical and other hazards (Ayi & Hon, 2018; Abu-Siniyeh & Al-Shehri, 2021). In parallel, biohazard risks were particularly prominent in biomedical laboratories, where exposure to hazardous biological materials posed a substantial threat to safety (AlShammari et al., 2021).

Within food processing and preparation contexts, microbial contamination and poor hygiene were identified as major determinants of risk. The presence of specific pathogens, such as *Bacillus cereus* and Norovirus, was frequently reported (Orou Seko et al., 2022; Chen et al., 2019; Bujang et al., 2023). These risks were often exacerbated by inadequate food handling techniques and deficient personal hygiene (Bujang et al., 2023; Compaore et al., 2022; Tian et al., 2022). Furthermore, cross-contamination was identified as a distinct but related risk factor that contributed significantly to the spread of foodborne pathogens in these settings (Bujang et al., 2023).

Ergonomic risks also emerged as a significant determinant, with studies highlighting the prevalence of musculoskeletal pain resulting from non-compliance with ergonomic principles and the performance of repetitive tasks (Kołcz et al., 2020; AlShammari et al., 2021). Psychological factors, such as stress linked to high workloads and the need for external assistance with complex cognitive tasks, were also identified as contributors to risk (Wang et al., 2019). Compounding these issues was the absence of a proactive safety culture. Multiple studies identified that a lack of consistent safety practices and a weak commitment from leadership served as significant barriers to establishing a safe working environment (Marin et al., 2019; Ayi & Hon, 2018).

Further determinants were identified at both the environmental and individual levels. At the environmental level, these included a lack of engineering controls, such as inadequate ventilation or physical barriers (Keckler et al., 2019), and the presence of high-risk zones where chemical, ergonomic, and fire hazards converged (Dehdashti et al., 2020). Specific to food contexts, seasonal factors were noted, with a higher risk of foodborne illness during warmer months (Xu & Yang, 2022).

At the individual and procedural level, a lack of real-world safety experience was a key issue in educational settings, limiting students' exposure to practical hazard scenarios (Willey et al., 2019). Deficiencies in specific practices, such as a lack of hand hygiene in cases involving zoonotic infections (Tian et al., 2022), and technical challenges like the difficulty in detecting contamination in surveillance tests (Davidi et al., 2021), also contributed to risk.

Finally, the review identified risks related to specific exposures and populations. These included exposure to organic dust and allergens in specialized industries like cannabis production (Davidson et al., 2018), cognitive impairments affecting task sequencing among individuals with neurological conditions (Wang et al., 2018), and dietary risks such as high sodium intake in school meals (Rito et al., 2020). A comprehensive summary of all identified risk determinants is presented in Table 2.

Table 2. Risk Determinants Identified in the Review

No.	Determinant	Description	References
1	Inadequate Safety Compliance	Inadequate compliance with safety regulations and inconsistent safety practices	Salazar-Escoboza et al., 2020; Ayi & Hon, 2018; Salazar-Escoboza et al., 2020
2	Limited Training	Limited training initiatives and inadequate safety training	Salazar-Escoboza et al., 2020; Cook-Shimanek et al., 2020; Willey et al., 2019
3	Chemical Hazards	High chemical risks, exposure to sensitizing chemicals, and chemical hazards	Pertiwi et al., 2021; Cook-Shimanek et al., 2020; AlShammari et al., 2021; Dehdashti et al., 2020
4	Microbial Contamination	High microbial contamination in food settings	Orou Seko et al., 2022; Compaore et al., 2022; Chen et al., 2019; Bujang et al., 2023
5	Poor Hygiene Practices	Poor hygiene practices in food handling and personal hygiene	Orou Seko et al., 2022; Bujang et al., 2023; Compaore et al., 2022; Qingmei Tian et al., 2022
6	Lack of PPE Usage	Insufficient or inconsistent use of Personal Protective Equipment (PPE)	Pertiwi et al., 2021; Ayi & Hon, 2018; Abu-Siniyeh & Al-Shehri, 2021
7	Ergonomic Risks	Musculoskeletal pain and ergonomic non-compliance	Anna Kołcz et al., 2020; AlShammari et al., 2021; Dehdashti et al., 2020
8	Cross-contamination	Risk of cross-contamination in food preparation settings	Bujang et al., 2023; Bujang et al., 2023
9	High Sodium Intake	High sodium levels in school meals	Rito et al., 2020
10	Limited Safety Awareness	Poor awareness of fire extinguisher use, limited proactive safety initiatives, and low safety awareness	Abu-Siniyeh & Al-Shehri, 2021; Luz S. Marin et al., 2019; Md. Khalid Hasan & Tahmina Younos, 2020
11	Biohazard Risks	Biohazard risks in laboratory environments	AlShammari et al., 2021
12	Psychological Stress	Stress and need for external assistance	Anna Kołcz et al., 2020; Jing Wang et al., 2018
13	Lack of Safety Culture	Lack of a proactive safety culture, inconsistent safety practices	Luz S. Marin et al., 2019; Ayi & Hon, 2018; Md. Khalid Hasan & Tahmina Younos, 2020

No.	Determinant	Description	References
14	Foodborne Pathogen Contamination	Contamination with foodborne pathogens such as Bacillus cereus, Norovirus	Chen et al., 2019; Bujang et al., 2023
15	Lack of Engineering Controls	Inconsistent use of engineering controls	Keckler et al., 2019
16	Lack of Real-world Safety Experience	Limited exposure to real-world safety practices and hazard analysis	Willey et al., 2019
17	Seasonal Food Safety Risks	Higher risk for foodborne illness during warm months	Xu & Yang, 2022
18	High Risk Areas in Labs	High-risk areas in labs and other facilities due to chemical, ergonomic, fire, electrical hazards	Dehdashti et al., 2020
19	Lack of Hand Hygiene	Failure to maintain proper hand hygiene	Qingmei Tian et al., 2022
20	Difficulty in Contamination Detection	Difficulty distinguishing between true positives and contamination	Davidi et al., 2021
21	Exposure to Dust and Pollen	Exposure to organic dust, allergenic pollen, and psychoactive substances	Davidson et al., 2018
22	Cognitive Impairments	Cognitive impairments affecting task sequencing	Jing Wang et al., 2018

Overall, this review underscores the diverse and interrelated nature of risk determinants affecting safety in laboratory environments, emphasizing the need for comprehensive training, improved safety culture, consistent use of PPE, and enhanced compliance with safety protocols to mitigate workplace accidents effectively, especially in food processing laboratory contexts.

Mitigation Strategies

Corresponding to the diverse risk determinants identified, the reviewed studies proposed a range of multifaceted mitigation strategies. These strategies were designed to address the various safety risks present in laboratory environments, including food processing labs, by targeting specific areas such as regulatory compliance, training, Personal Protective Equipment (PPE) utilization, and hygiene practices. The overarching goal of these interventions was to create a safer working environment by reducing hazard exposure, strengthening the safety culture, and enhancing overall safety awareness. This section details the specific mitigation strategies identified, which span from educational initiatives to procedural modifications in laboratory safety protocols.

Table 3. Mitigation Strategies Identified in the Review

No.	Mitigation Theme	Description	References
1	Training and Education	Enhanced safety training, training on ergonomic principles, hygiene training, OSH awareness, emphasis on safety training, educational talks for food handlers	Salazar-Escoboza et al., 2020; Pertiwi et al., 2021; Orou Seko et al., 2022; Bujang et al., 2023; Anna Kołcz et al., 2020; Keckler et al., 2019; Md. Khalid Hasan & Tahmina Younos, 2020; Abu-Siniyeh & Al-Shehri, 2021; Salazar-Escoboza et al., 2020; Rito et al., 2020; Compaore et al., 2022
2	Use of PPE and Safety Protocols	Regular PPE usage enforcement, provision of PPE, control measures with PPE, implementation of safety protocols	Pertiwi et al., 2021; Cook-Shimanek et al., 2020; AlShammari et al., 2021; Davidson et al., 2018
3	Safety Leadership and Climate	Emphasis on safety leadership by staff, strengthening safety attitudes, implementation of HSE guidelines, increased safety monitoring, development of safety survey tools	Salazar-Escoboza et al., 2020; Salazar-Escoboza et al., 2020; Keckler et al., 2019; Ayi & Hon, 2018
4	Food Safety and Hygiene	Monitoring food safety practices, provision of hygiene kits, food handler education, isolation of cases, closure of high-risk food stalls	Orou Seko et al., 2022; Bujang et al., 2023; Chen et al., 2019; Compaore et al., 2022
5	Implementation of Standard Operating Procedures (SOPs)	Improved testing protocols, implementing SOPs, clearing fume hoods for chemical work, frequent safety inspections	Pertiwi et al., 2021; Cook-Shimanek et al., 2020; AlShammari et al., 2021
6	Laboratory Safety Management	Development of annual safety survey, introduction of 3D risk assessment, stricter lab protocols for handling DNA	Keckler et al., 2019; Davidi et al., 2021
7	Ergonomic Improvements	Training on ergonomic principles, body composition monitoring, risk reduction training	Anna Kołcz et al., 2020; Dehdashti et al., 2020

No.	Mitigation Theme	Description	References
8	Specific Medical Interventions	Removal of worms using ophthalmic forceps, use of eye drops, context-aware automatic prompting	Qingmei Tian et al., 2022; Jing Wang et al., 2018
9	Risk Assessment Tools	Use of checklist, Bowtie, HAZOP analysis, industrial mentorship for practical exposure	Willey et al., 2019
10	Hygiene Checks	Vendor training in hygiene, regular quality checks, improved food handling practices, sanitation measures	Compaore et al., 2022; Xu & Yang, 2022; Chen et al., 2019
11	Administrative and Policy Measures	Adoption of interim exposure standards, safety climate survey (CLASS) designed for college settings, policy enforcement	Davidson et al., 2018; Luz S. Marin et al., 2019; Xu & Yang, 2022
12	Facility and Environmental Changes	Suspension of canteen activities, closure of high-risk stalls, improved menu development	Bujang et al., 2023; Chen et al., 2019; Rito et al., 2020

The mitigation strategies identified in the literature can be broadly categorized into several interconnected themes, reflecting a comprehensive, multi-layered approach to enhancing laboratory safety. A foundational theme was Training and Education, which encompassed enhanced safety training, ergonomics instruction, hygiene awareness programs, and targeted educational talks aimed at improving the knowledge and risk perception of both students and workers (Salazar-Escoboza et al., 2020; Pertiwi et al., 2021; Orou Seko et al., 2022). Closely related was the implementation of, and adherence to, clear Protocols and the use of Personal Protective Equipment (PPE). This included enforcing PPE utilization to control chemical and physical hazards and applying robust Standard Operating Procedures (SOPs) for specific tasks (Pertiwi et al., 2021; Cook-Shimanek et al., 2020; AlShammari et al., 2021).

Beyond individual compliance, fostering a positive Safety Leadership and Climate was another crucial strategy. This was achieved through visible safety leadership, initiatives to improve safety attitudes, and the use of climate assessment tools to shape safer behaviors (Salazar-Escoboza et al., 2020; Keckler et al., 2019). These broader cultural efforts were supported by specific procedural controls. For instance, in food-related settings, Food Hygiene Practices like handler education were applied (Orou Seko et al., 2022; Chen et al., 2019), while in laboratory contexts, formal Laboratory Safety Management systems and Ergonomic Improvements were implemented (Keckler et al., 2019; Davidi et al., 2021; Kołcz et al., 2020).

Finally, a combination of prospective assessment and definitive control measures was evident. The use of formal Risk Assessment Tools, such as checklists and HAZOP analysis, served as a key strategy for identifying and mitigating hazards (Willey et al., 2019). These were complemented by Administrative and Policy Measures, including the adoption of interim exposure standards and the deployment of safety surveys, to enforce and monitor the safety environment (Davidson et al., 2018; Marin et al., 2019). In cases requiring direct intervention, Facility and Environmental Changes, such as the suspension of high-risk canteen activities or the improvement of school menus, were employed as a decisive control measure to create a safer environment for students (Bujang et al., 2023; Chen et al., 2019; Rito et al., 2020).

DISCUSSION

This systematic review synthesized evidence from 23 primary studies to identify key risk determinants and mitigation strategies concerning occupational incidents among students in laboratory settings. The findings reveal a complex safety landscape where human factors, environmental conditions, and organizational culture are deeply intertwined.

Principal Findings and Interpretation

The most prominent risk determinant identified was a pervasive lack of safety compliance and awareness (Salazar-Escoboza et al., 2020; Ayi & Hon, 2018; Hasan & Younos, 2020). Supported by evidence from studies of predominantly moderate methodological quality, this finding suggests the issue extends beyond mere non-adherence to rules, pointing instead to a deeper challenge of behavioral and cultural norms. This problem transcends specific laboratory types, manifesting in chemical, biomedical, and food processing contexts alike. This observation aligns with established safety literature, which posits that a weak "safety climate"—wherein safety is not perceived as a shared core value—is a primary predictor of occupational incidents (Zohar, 2010).

Notably, while specific hazards like chemical and microbial risks were frequently reported, the effectiveness of mitigation strategies was seldom reliant on a single solution. Instead, successful mitigation, as demonstrated in high-quality studies like the low-risk RCT by Orou Seko et al. (2022), typically involved multi-component interventions that combined training, equipment provision, and ongoing monitoring. This strongly suggests that isolated, single-point solutions (e.g., providing PPE alone) are substantially less effective than integrated, systemic safety programs.

A critical insight from the quality appraisal is the methodological composition of the evidence base. The majority of the included studies were cross-sectional surveys and case reports, designs that inherently carry a moderate to high risk of bias. While these study designs are valuable for identifying potential associations and generating hypotheses, they cannot establish causality. For instance, although a link was found between poor ergonomic practices and musculoskeletal pain (Kołcz et al., 2020), the cross-sectional nature of the study makes it impossible to rule out other confounding variables. Furthermore, the prevalent reliance on self-reported data in many of these studies introduces a potential for reporting bias.

Implications for Practice and Policy

The findings of this review yield several actionable implications for higher education institutions and policymakers. First, institutions must move beyond passive, compliance-focused training. The evidence suggests a clear need to shift from perfunctory safety briefings to a continuous, interactive training model. This should include hands-on simulations, peer-led safety workshops, and mandatory refresher courses to address the recurring issue of insufficient training identified in multiple studies (Pertiwi et al., 2021; Willey et al., 2020).

Second, it is imperative to foster a proactive safety culture. This requires a top-down commitment where laboratory managers and academic supervisors actively model safe behaviors and consistently enforce safety protocols. Leadership is crucial in transforming safety from a matter of compliance to a shared value. Implementing validated tools, such as the Chemistry Laboratory Safety Climate Survey (CLASS), can provide institutions with a benchmark to measure their safety culture and identify specific areas for improvement (Marin et al., 2019).

Third, institutions should systematically implement the "Hierarchy of Controls," a foundational principle of occupational safety and health (OSH). Rather than defaulting to Personal Protective Equipment (PPE) as the primary solution, this principle mandates prioritizing higher-level controls. The focus should first be on elimination or substitution of hazards (e.g., using less hazardous chemicals). This should be followed by the implementation of engineering controls (e.g., improving ventilation), then administrative controls (e.g., robust SOPs), and only then, as the final line of defense, ensuring the proper use of PPE.

Limitations of the Review

Several limitations of this review must be acknowledged. First, the search was confined to two databases (PubMed and Scopus) and restricted to English-language publications. This may have introduced publication and language bias, potentially leading to the omission of relevant studies from other databases or those published in other languages. Second, the selected timeframe (2019–2024) necessarily excludes older, foundational research that may still hold relevance. Third, the exclusion of articles where the full text was not accessible may have introduced a selection bias. Finally, the significant heterogeneity of the included studies in terms of design, setting, and outcomes precluded the possibility of a quantitative meta-analysis. Consequently, the synthesis was conducted narratively, and the interpretation of the findings is therefore contingent on the methodological quality of the primary studies, many of which, as noted, carry a moderate risk of bias.

CONCLUSION

This systematic review concludes that occupational incidents among students in laboratory environments are driven by a consistent set of risk determinants, primarily inadequate safety compliance, limited training, and inconsistent safety culture. These factors are compounded by specific hazards such as chemical exposure, microbial contamination, and ergonomic risks. The evidence demonstrates that student safety is not a passive state but an outcome of active, systemic efforts.

The most effective mitigation strategies are comprehensive and multi-layered, moving beyond simple rule enforcement. The evidence strongly supports a combination of targeted educational initiatives, the consistent use and enforcement of Personal Protective Equipment (PPE), the development of a proactive safety leadership and culture, and adherence to clear Standard Operating Procedures (SOPs). A holistic approach that integrates these elements is crucial for creating genuinely safe laboratory environments.

Future research should aim to overcome the limitations identified in this review. Priority should be given to longitudinal studies that can establish the long-term effectiveness of mitigation strategies and intervention studies with robust designs (e.g., RCTs) to provide higher-quality evidence. Expanding research to include a wider range of databases and non-English literature would provide a more globally comprehensive understanding. Finally, more research is needed to explore the practical application and effectiveness of the "hierarchy of controls" within diverse academic laboratory settings to ensure students are protected from the widest possible range of risks.

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