Chapter 2

Toxin-Free Training: Chemical Pollution in Gyms and Green Hygiene Approaches

Mustafa Ceylan[1]

Necip Zeki Budak[2]

Elif Aktürk Bozdemir[3]

Abstract

Modern sports facilities are designed to promote health and performance, yet the cleaning and disinfection practices commonly employed may expose athletes to a substantial chemical burden. The intensive use of quaternary ammonium compounds and chlorine-based agents, combined with elevated levels of volatile organic compounds, particulate matter, disinfection byproducts, and CO_2, can compromise indoor air quality and adversely affect respiratory function, skin barrier integrity, cognitive performance, and overall athletic capacity. This chapter summarizes the main chemical agents used in gyms, outlines their behavior in enclosed environments, and discusses their potential health and performance implications for athletes. It then explores, within the framework of green chemistry principles, the role of enzymatic and probiotic cleaning approaches in reducing toxic load while maintaining hygiene standards. An integrated "Green Hygiene Strategy" tailored to sports facilities is proposed, along with practical recommendations for facility managers, cleaning staff, and athletes. The chapter concludes by emphasizing the need to move towards genuinely "toxin-free" training environments.

1. Introduction: The Hygiene Paradox in Modern Sports Facilities

Sports facilities, seen as symbols of health and fitness, expose their users to a serious chemical threat without them realizing it. Recent environmental toxicology data show that indoor air quality in these enclosed spaces can reach levels even more hazardous than those in high-traffic outdoor environments.

1 Tokat Gaziosmanpaşa University, mustafac.ceylan@gop.edu.tr , 0000-0002-9184-4385

2 Tokat Gaziosmanpaşa University,necipzekibudak@gmail.com , 0009-0002-3286-8448

3 Tokat Gaziosmanpaşa University, elif.akturkbozdemir@gop.edu.tr, 0009-0007-7760-8574

https://doi.org/10.58830/ozgur.pub1141.c4699

Aggressive disinfection protocols implemented to protect athletes from disease have, unfortunately, become the primary source of contamination, poisoning them.

The most striking findings on this subject come from the comprehensive analyses conducted by Peixoto and his team (2023) in health clubs. The study documents that concentrations of particulate matter (PM10, PM2.5), carbon dioxide (CO_2), formaldehyde, and volatile organic compounds (VOCs) in gym atmospheres exceed threshold values considered safe for human health. Particularly in cardiovascular exercise areas, the intensity generated by exerting athletes and the inadequate ventilation capacity in studios transform this pollution picture into a public health problem.

This toxic atmosphere in gyms cannot be explained solely by dirty air seeping in from outside. The interaction between chemicals released into the air from cleaning products and human metabolic activities, such as perspiration and respiration, turns the environment into a complex chemical reactor. Salonen and colleagues' (2020) systematic review highlights that CO_2 and particulate matter are the most significant pollutants, particularly in fitness centers. It highlights that exposure to these pollutants can have adverse effects on respiratory function, skin barrier integrity, and overall well-being (Salonen et al., 2020).

More concerning, the Green Science Policy Institute (2024) highlights that these chemicals, mainly when used at high frequencies and without adequate contact time, may increase chemical exposure risks while only marginally improving disinfection efficacy. Various experimental and epidemiological studies indicate that these compounds have the potential to cause toxic effects on the skin, respiratory system, immune system, and reproductive system. These substances have been shown to have toxic effects on the skin, lungs, immune system, and reproductive system, in addition to triggering antibiotic resistance. In light of this data, abandoning traditional hygiene habits and adopting new strategies centered on "green chemistry" is an inevitable necessity for sustainable sports management (Budak, 2025; Budak & Aktürk Bozdemir, 2025; Budak & Keçeci Sarıkaya, 2024).

2. Current Situation Analysis: Chemical Load and Indoor Environment Dynamics

To accurately analyze the gym atmosphere, it is necessary to understand the structure of the agents used for hygiene and their behavior in closed environments.

2.1. Quaternary Ammonium Compounds (QACs): The Invisible Danger

QAC compounds such as benzalkonium chloride (BAC) and didecyldimethylammonium chloride (DDAC), which provide the characteristic "hygienic" smell in sports facilities, are indispensable in the industry due to their broad antimicrobial spectrum. However, the Green Science Policy Institute (2024) states that when these chemicals are misapplied, they do not provide effective disinfection but instead increase the risk of chemical exposure.

QACs interact with the cell membrane lipid layer, disrupting membrane integrity; unfortunately, this cytotoxic effect also applies to human cells. Dermal contact with residues

Left on surfaces can cause contact dermatitis and allergic reactions, while inhalation of evaporating chemicals can exacerbate asthma symptoms. Increased respiratory rate (tidal volume) during exercise causes athletes to draw this toxic load into the deepest parts of their lungs. VOC levels peak immediately after cleaning, leaving athletes exposed to chronic levels.

2.2. Chlorine-Based Agents and Disinfection Byproducts (DBPs)

Chlorine-based agents, such as sodium hypochlorite, which are primarily used in pool complexes, undergo toxic transformation when they react with organic matter (including sweat, urine, and skin flakes) in water and air. The most dangerous of the resulting "Disinfection Byproducts" (DBPs) is nitrogen trichloride (NCl_3). Salonen et al. (2020) emphasize that this compound, which causes eye irritation and shortness of breath at the poolside, is strongly associated with an increased risk of asthma in swimmers. Furthermore, some compounds formed as a result of these reactions, such as trihalomethanes, have been classified as possible carcinogens by the International Agency for Research on Cancer (IARC).

2.3. Complex Atmospheric Mixture: VOCs and Particulate Matter

Pollution is not limited to cleaning agents. Peixoto and colleagues (2023) found that carcinogenic VOCs such as formaldehyde, benzene, and toluene, emitted from building materials, equipment, and personal care products, are present in high concentrations in health clubs. When combined with particulate matter (PM2.5) accumulating in the environment due to inadequate filtration systems, this creates an environment that can reach the alveoli of the lungs and trigger systemic inflammation. CO_2 levels above 1000 ppm in crowded rooms are a concrete indicator of inadequate

ventilation and are associated with decreased cognitive performance and feelings of fatigue.

3. Effects on Athlete Health and Performance

Chemical pollutants directly undermine performance by causing acute and chronic adaptation problems in athlete physiology.

3.1. Respiratory System: The "Athlete's Asthma" Phenomenon

Chemical pollutants directly attack the respiratory tract epithelium, disrupting barrier integrity and paving the way for the phenomenon known as "athlete's asthma." As noted by Salonen et al. (2020), exposure to NCl_3 and epithelial damage may trigger the release of pro-inflammatory cytokines, making the airways hypersensitive and paving the way for exercise-related bronchial hyperreactivity. During exercise, minute ventilation increases up to 20 times, and mouth breathing becomes predominant, bypassing the nose's natural filtration mechanism and allowing irritants to reach the lower respiratory tract directly.

3.2. Dermatological Effects and Microbiota Damage

The skin is the first line of defense against chemical agents. However, QACs disrupt the skin microbiota, leading to a state of "dysbiosis." Staphylococcus and Corynebacterium species found on the skin are commensal microorganisms that play a crucial role in maintaining the skin's barrier function. It is believed that aggressive chemical cleaning practices may have a suppressive effect on this protective flora, thereby facilitating the colonization of pathogens. Additionally, chlorine-induced oxidative damage breaks down skin proteins, thereby increasing the risk of chronic dryness and chemical dermatitis.

3.3. Performance Limits: VO_2max and Fatigue

Even the slightest impairment in respiratory function directly results in a decrease in aerobic capacity (VO_2max). As emphasized by Peixoto et al. (2023), high CO_2 levels stimulate the respiratory center, causing early fatigue. It is biologically plausible that systemic inflammation triggered by VOCs and particulate matter could have long-term adverse effects on muscle protein synthesis and recovery processes. However, studies demonstrating a direct relationship between gym exposure and performance parameters remain limited.

4. Solution: The Green Hygiene Revolution and Biological Cleaning

In response to the risks posed by traditional methods, Paul Anastas and John Warner's "Green Chemistry" principles offer a scientific and sustainable solution for sports facilities (Budak & Keçeci Sarıkaya, 2024).

4.1. Enzymatic Cleaners

Enzymatic cleaners utilize enzymes, such as proteases and lipases, to break down organic contaminants (including sweat, grease, and blood) through a process known as biocatalysis. Manufacturer technical bulletins indicate that enzymatic cleaners can effectively remove organic waste without leaving toxic residues, thereby supporting improved indoor air quality (Multi-Clean, 2019). These claims require more comprehensive evaluation through independent studies. However, it should be remembered that enzymes are not alive and can lose their activity (inhibition) when mixed with strong chemical disinfectants; therefore, application protocols must be carefully designed to prevent this loss of activity. Kato et al. (2015) demonstrated that, in the context of reprocessing medical devices, adding a disinfectant agent to enzymatic detergent formulations enhances disinfection power but reduces cleaning effectiveness. Therefore, they emphasize that a delicate balance between cleaning and disinfection is necessary in "dual-function" formulations (Kato et al., 2015).

4.2. Probiotic Hygiene and Biofilm Control

One of the most notable innovations in hygiene technology is the use of probiotic cleaning approaches, which utilize selected beneficial microorganisms, such as Bacillus species. In these products, spore-forming bacteria that can permanently colonize gym surfaces are applied to the environment together with the detergent matrix. The goal is to restructure the surface microbiome into a more resilient and less pathogenic equilibrium rather than merely reducing it temporarily.

Companies developing probiotic cleaning products (e.g., Genesis Biosciences, 2023; Ingenious Probiotics, n.d.) report that this approach works primarily on the principle of "competitive exclusion." According to this, beneficial microorganisms attach to the surface and compete with pathogenic microorganisms for food sources and attachment sites; over time, the pathogen load decreases, and a more stable and predictable microbial community forms on the surface. According to manufacturer data, one of the most critical advantages is their ability to contribute to the mechanical and biological breakdown of resistant biofilm layers commonly found on shower areas, floors,

and equipment surfaces (Genesis Biosciences, 2023; Ingenious Probiotics, n.d.). These claims are particularly noteworthy for gym environments, where organic loads and biofilms are dense; however, manufacturer claims need to be supported by independent, peer-reviewed studies.

Scientific evidence regarding microbiota-based cleaning approaches has begun to accumulate, particularly in healthcare settings. D'Accolti et al. (2019) demonstrated that probiotic cleaning systems implemented in hospital settings can reduce surface pathogen load more persistently than conventional chemical cleaning protocols and limit the spread of antimicrobial resistance genes. These studies reveal that probiotic cleaning strategies can modulate surface microflora over a more extended period, rather than merely creating an immediate disinfection effect. However, the number of studies directly evaluating probiotic cleaning applications in environments such as sports facilities and fitness centers is still limited; therefore, a more detailed examination of the risk profiles and activity levels specific to health clubs is required.

A key consideration in comparing probiotic and conventional chemical disinfection approaches is the duration of effect and potential side effects. Chlorine-based disinfectants and products containing QACs can provide a high level of microbial killing power when applied; however, their effects generally last only minutes to hours, while volatile organic compounds, disinfection by-products, and toxic residues can create additional burdens on human health and indoor air quality. Probiotic cleaning approaches, on the other hand, offer a potential "residual effect" that starts more slowly but continues as long as probiotic microorganisms are present on the surface. Current data suggest that this residual effect may be particularly meaningful in terms of bacterial and fungal load (D'Accolti et al., 2019), while indicating that the effects on enveloped viruses and other pathogen groups need to be evaluated separately for different formulations.

In the context of sports facilities, it is more appropriate to position probiotic cleaning products not as a direct "stand-alone disinfectant" but as a component of an integrated green hygiene strategy. First, mechanical cleaning and enzymatic cleaning should be used to remove organic load and coarse dirt; then, probiotic products should be used to shift the surface microbiome to a more balanced structure, especially on surfaces with high contact intensity but where chemical load needs to be reduced (floors, changing rooms, shower areas, outer surfaces of cardio equipment, etc.). This approach can reduce dependence on traditional high-toxicity disinfectants while contributing to the long-term control of resistant biofilms and pathogen load.

In conclusion, probiotic hygiene approaches are an innovative tool with the potential to reduce chemical pollution and manage surface microbiota in a more sustainable way in sports facilities. However, to fully realize this potential, there is a need for controlled field studies in health clubs, research comparing the safety and efficacy profiles of different probiotic formulations, and multidisciplinary studies evaluating user acceptance.

5. Conclusions and Recommendations

The "hygiene paradox" we face in modern sports facilities is a significant public health and environmental sustainability issue that warrants urgent attention, given the available scientific evidence. Evidence presented by Peixoto et al. (2023), Salonen et al. (2020), and the Green Science Policy Institute (2024) demonstrates that traditional quaternary ammonium compounds (QACs) and chlorine-based cleaning regimes need to be reevaluated in terms of both human health and environmental sustainability and replaced with risk-reducing alternatives wherever possible. The adverse effects of these chemicals on indoor air quality can lead to respiratory irritation, dermatological problems, and decreased cognitive function, all of which directly impact an athlete's health and performance.

The solution to this problem lies in sports facility management adopting an integrated "Green Hygiene Strategy." This strategy should be a multi-layered approach that aims not only to reduce chemical use but also to optimize indoor air quality and promote sustainable cleaning practices. Below are the key components of this strategy and recommendations for relevant stakeholders:

5.1. Recommendations for Facility Managers and Operators

1. **Reviewing and Reducing the Chemical Inventory:**
    - Gradually phasing out highly toxic cleaning and disinfection agents such as quaternary ammonium compounds (QACs), aldehydes, phenols, and high-concentration chlorine-based products from inventory.
    - Preferring products with low volatile organic compound (VOC) content, that are biodegradable, and have environmentally friendly certifications.
2. **Prioritizing Mechanical Cleaning:**
    - The use of adequate mechanical cleaning equipment, such as HEPA-filtered vacuum cleaners and microfiber cloths.

- Implementation of regular and systematic cleaning programs to reduce dust and particulate matter accumulation.

3. **Integration of Enzymatic and Probiotic Cleaning Systems:**
   - Use of enzymatic detergents in the pre-cleaning stage to reduce organic dirt load.
   - Using probiotic cleaning products to achieve a more balanced surface microbiome, especially on surfaces with high contact intensity but where chemical exposure needs to be reduced (floors, changing rooms, shower areas, equipment exteriors).
4. **Ventilation and Indoor Air Quality Monitoring:**
   - Regular maintenance of mechanical ventilation systems and filter replacement.
   - Periodic monitoring of CO_2, particulate matter ($PM_{2.5}$, PM_{10}), and total volatile organic compound (TVOC) levels, and installation of alarm systems above specified threshold values.
   - Optimizing ventilation rates according to the facility's usage intensity.
5. **Staff Training:**
   - Comprehensive training of cleaning personnel on green hygiene principles, proper use of new products, dosing, and application techniques.
   - Raising awareness about chemical exposure risks and the use of personal protective equipment.

5.2. Recommendations for Athletes

6. **Increasing Personal Awareness:**
   - Avoid training during peak hours after cleaning (especially the first few hours immediately after disinfection) or choose areas with adequate ventilation.
   - Pay attention to personal hygiene rules (hand washing, wiping equipment with a personal towel).
7. **Skin Barrier Protection Measures:**
   - Use pH-balanced cleansers that do not dry out the skin when showering after exercise.

- Protect the skin with moisturizers that strengthen the skin barrier.

5.3. Recommendations for Policy Makers and Researchers

8. **Development of Legal Regulations:**
   - Revising indoor air quality standards and cleaning protocols for sports facilities based on current scientific data.
   - Promoting green hygiene products and restricting the use of toxic chemicals.
9. **Supporting Multidisciplinary Research:**
   - Conducting controlled field studies comparing the effects of different cleaning approaches (chemical, enzymatic, probiotic) in sports facilities on indoor air quality, surface microbiome, athlete health, and performance.
   - Supporting epidemiological studies examining the effects of long-term exposure on chronic health outcomes.

The sports facilities of the future must be "non-toxic" spaces where not only physical capacity but also environmental health is optimized. This transformation is not only a scientific necessity but also an ethical responsibility towards the health of athletes and the planet's sustainability.

7. Conclusion

The transition from chemically intensive disinfection to a "Green Hygiene" paradigm is no longer a discretionary choice but a physiological necessity for the modern sports industry. As detailed throughout this chapter, the respiratory and dermatological burdens imposed by traditional quaternary ammonium compounds and chlorine-based agents create a paradox in which the need for hygiene maintenance compromises the pursuit of health. The adoption of Green Chemistry principles—specifically through the integration of enzymatic and probiotic technologies—offers a scientifically viable pathway to mitigate these toxic exposures without sacrificing microbial safety. By shifting the focus from "sterile destruction" to "microbial balance," facility managers can optimize indoor air quality and protect the biological integrity of athletes. Ultimately, realizing the vision of "toxin-free training" requires a holistic commitment to sustainable practices, ensuring that sports environments support, rather than undermine, human performance and environmental well-being.

References

Budak, Y. (2025). Climate law: Necessity or opportunity for Türkiye? Sustainable environmental vision with green chemistry. International Journal of Energy Studies, 10(3), 1229-1258. https://doi.org/10.58559/ijes.1685452

Budak, Y., & Aktürk Bozdemir, E. (2025). Sustainable transformation with green chemistry: Innovative deep eutectic solvents for levulinic acid production from pine sawdust. Subsequent Research, 2(3), Article 100706.

Budak, Y., & Keçeci Sarıkaya, M. (2024). Zero waste and green transformation: Environmentally friendly cosmetic and cleaning products for Turkey's future. Gaziosmanpasa Journal of Scientific Research, 13(3), 145-155.

D'Accolti, M., Soffritti, I., Mazzacane, S., & Caselli, E. (2019). Fighting AMR in the Healthcare Environment: Microbiome-Based Sanitation Approaches and Monitoring Tools. *International Journal of Molecular Sciences*, *20*(7), 1535.

Genesis Biosciences. (2023). *Probiotic cleaners vs enzymatic cleaners: What is the difference?*

Genesis Biosciences Blog.

Green Science Policy Institute. (2024). *Quaternary ammonium compounds (QACs): Health concerns and safer alternatives.* Green Science Policy Institute Report.

Ingenious Probiotics. (n.d.). *Probiotic cleaning: The future of sustainable hygiene.* Ingenious Probiotics Educational Resources.

Kato Y, Toga Y, Oda Y, Kawamukai E, Hirata Y. *Study of enzymatic detergents with both cleaning efficacy and disinfecting action for medical devices.* Antimicrobial Resistance and Infection Control. 2015;4(Suppl 1):P37.

Multi-Clean. (2019). *Bio-enzyme products: Harnessing naturally occurring microbes for effective cleaning.* Multi-Clean Technical Bulletin.

Peixoto, C., Pereira, M. do C., Morais, S., & Slezakova, K. (2023). Assessment of indoor air quality in health clubs: insights into (ultra)fine and coarse particles and gaseous pollutants. *Frontiers in Public Health*, 11, 1310215.

Salonen, H., Salthammer, T., & Morawska, L. (2020). Human Exposure to Air Contaminants in Sports Environments. *Indoor Air*, 30(6), 1109–1129.