Determining Factors of Microbial Air Quality of Pleurotus Ostreatus Cultivation Facility

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ABSTRACT

Microbial air quality is a critical determinant of environmental hygiene and production efficiency in Pleurotus ostreatus cultivation facilities, yet it remains insufficiently addressed in many commercial systems. Airborne microorganisms, including bacterial cells and fungal spores, originate from multiple sources such as growth substrates, mushroom biomass, irrigation practices, human activity, ventilation systems, and the surrounding outdoor environment. Once aerosolized, these bioaerosols are transported, deposited, or removed through dynamic indoor air processes influenced by environmental and operational conditions

The objective of this literature review was to synthesize current scientific knowledge on the factors determining microbial air quality in P. ostreatus cultivation facilities and to evaluate their implications for contamination control and cultivation performance. A structured literature search was conducted across major scientific databases, including Google Scholar, Scopus, and PubMed, focusing on peer-reviewed studies published between 2015 and 2025. Relevant articles were selected based on predefined inclusion criteria and analyzed using a thematic synthesis approach.

The review findings Indicate that microbial air quality is shaped by a complex interaction of physical environmental factors (temperature, relative humidity, airflow patterns), operational facility characteristics (air exchange rates, mechanical ventilation systems, filtration efficiency), biological emission sources (substrates, mycelial growth, spore release), and external contamination pathways. Poorly managed air quality was consistently associated with increased contamination risks, competitive microbial growth, and disease outbreaks such as green mold, reduced yields, and compromised mushroom quality.

In conclusion, maintaining optimal microbial air quality requires integrated management strategies combining effective ventilation design, controlled environmental conditions, proper sanitation, and informed operational practices. Addressing current knowledge gaps through targeted research on mushroom-specific bio-aerosol dynamics will further enhance sustainable and safe P. ostreatus production systems.

Keywords: Pleurotus ostreatus; microbial air quality; bioaerosols; indoor cultivation; ventilation systems; contamination control

INTRODUCTION

Background to Pleurotus ostreatus Cultivation

The oyster mushroom (Pleurotus ostreatus) is one of the most extensively cultivated edible mushrooms worldwide due to its adaptability to diverse substrates, it's relatively low production cost, and it's high nutritional value. In recent years, its cultivation has grown rapidly, particularly in developing countries, where it serves as both a food source and an income-generating opportunity. The mushroom is rich in dietary fiber, proteins, vitamins, and biologically active compounds like antioxidants that contribute to human health, making it increasingly attractive to consumers and producers alike (Rashad et al., 2024).

Commercial production of P. ostreatus is typically carried out in enclosed or semi-enclosed facilities where environmental parameters are closely monitored. These parameters include gaseous composition, temperature, light, and relative humidity. Among these factors, air quality plays an important but often overlooked role in P ostreatus cultivation. Air quality directly influences microbial dynamics within the cultivation environment where environmental monitoring and control are important for good yield (Chen et al., 2022; Ficociello et al., 2019).

Importance of Air Quality in Mushroom Cultivation Facilities

Air within mushroom cultivation facilities contains suspended biological particles collectively referred to as bio-aerosols, which may include fungal spores, bacterial cells, and fragments of microbial origin. These airborne microorganisms can arise from multiple sources such as growth substrates, casing materials used, irrigation water, and workers' activities in cultivation facility, and the surrounding outdoor environment. Once airborne, these microbes can circulate within the facility and settle on cultivation surfaces, substrates, or on the developing fruiting bodies of the mushrooms (Kembel et al., 2015).

Microbial air quality is particularly critical in mushroom production systems because mushrooms lack protective barriers and are highly susceptible to microbial competition. Studies have shown that elevated concentrations of airborne bacteria and fungi can increase the likelihood of contamination events, leading to reduced yield, altered morphology, or complete crop failure (Skarżyńska et al., 2013). In addition, excessive bio-aerosols loads in cultivation facility have been associated with occupational health concerns among mushroom farm workers, including respiratory irritation and allergic reactions (Eduard et al., 2009).

Despite its undeniable importance, air quality management in mushroom facilities often focuses mainly on carbon dioxide control and ventilation rates, while the microbial composition of air receives comparatively little attention.

Problem Statement and Research Focus

Available studies show that the air of mushroom cultivation facilities frequently harbors diverse microbial populations, including bacterial genera such as Pseudomonas and fungal genera such as Penicillium and Aspergillus (Hayes et al., 2014). These microorganisms may originate from decomposing substrates or external air and can persist within indoor cultivation environments (Skarżyńska et al., 2013). However, much of the existing research addresses general indoor air microbiology or focuses on button mushroom (Agaricus bisporus) systems, with limited emphasis on Pleurotus ostreatus facilities.

Furthermore, environmental and operational conditions such as temperature, humidity, ventilation efficiency, and human activity have been shown to influence airborne microbial concentrations in indoor agricultural settings (Hospodsky et al., 2010). The relative contribution of these factors within Pleurotus cultivation houses remains insufficiently synthesized in the literature, creating a gap in knowledge that may hinder effective contamination control and facility optimization.

Aim and Scope of the Review

This literature review seeks to examine and synthesize published evidence on the determinants of microbial air quality in Pleurotus ostreatus cultivation facilities. Specifically, it aims to identify key physical, biological, and operational factors that influence airborne bacterial and fungal populations within mushroom houses. By integrating findings from microbiology, environmental science, and agricultural research, the review intends to provide an understanding of how microbial air quality is shaped in these environments.

The scope of the review is limited to peer-reviewed and publicly accessible studies published between 2000 and 2025, with emphasis on research relevant to indoor mushroom cultivation systems. The findings are expected to inform better facility design, management practices, and future experimental investigations.

METHODOLOGY

Search Strategy and Database Selection

This study adopted a narrative literature review methodology, selected to enable a comprehensive and interpretive synthesis of research findings from diverse but related fields, including microbiology, indoor air quality, agricultural biotechnology, and mushroom cultivation systems. This approach was considered appropriate given the interdisciplinary nature of microbial air quality research and the limited number of studies focusing exclusively on Pleurotus ostreatus cultivation facilities.

A systematic literature search was conducted using major scientific and academic databases, namely:

- Google Scholar
- PubMed
- Research gate
- Web of Science
- ScienceDirect
- MDPI journal platform

These databases were chosen due to their extensive coverage of peer-reviewed journals in microbiology, environmental science, indoor air quality, and agricultural research.

The search strategy employed a combination of relevant keywords, including:

Microbial air quality, airborne microorganisms, bioaerosols, mushroom cultivation, Pleurotus ostreatus, oyster mushroom, indoor air, cultivation facility, controlled environment, temperature, humidity, ventilation and environmental factors.

Searches were limited to studies published between 2015 and 2025 to ensure that the review reflects current scientific understanding and practices.

Inclusion and Exclusion Criteria

To ensure relevance and quality, retrieved articles were screened using predefined inclusion and exclusion criteria.

Inclusion criteria: Peer-reviewed journal articles, review papers, and relevant conference proceedings and studies published between 2000 and 2025.

Research addressing:

Microbial air quality or bioaerosols in indoor environments, environmental or operational factors influencing airborne microbial populations, mushroom cultivation systems, particularly Pleurotus ostreatus, or comparable indoor agricultural facilities, articles written in English, studies providing empirical data, methodological descriptions, or analytical discussions relevant to airborne bacteria or fungi.

Exclusion criteria:

- Studies published before 2000.

- Research unrelated to biological air contaminants (e.g., studies focusing solely on chemical air pollutants).
- Non-scientific publications, opinion pieces, editorials, or unpublished theses without peer review.
- Studies lacking sufficient methodological clarity or relevance to cultivation environments.

Synthesis Approach for Thematic Analysis

The selected literature was analyzed using a thematic synthesis approach. This involved a process of reading, comparison, and categorization to identify recurring concepts and relationships across studies.

Key themes were developed based on:

Environmental determinants (e.g., temperature, relative humidity), facility design and ventilation characteristics, biological sources of airborne microbes (e.g., substrates, mushroom biomass) and operational practices and human activity within cultivation facilities.

Understanding Microbial Air Quality in Mushroom Cultivation

This section explains key concepts and mechanisms underlying microbial air quality which is a foundation for reviewing determinants of airborne microbes in Pleurotus ostreatus cultivation facilities.

Definitions and Key Concepts

In controlled environments such as mushroom cultivation facilities, air quality includes biological as well as physical and chemical components. The portion of air pollution that contains biological entities is known as bioaerosols. Bioaerosols are airborne particles of biological origin, which include bacteria, fungi, spores, viruses, pollen, and fragments of microbial cells. They suspend in air and travel varying distances depending on their size and the environmental conditions available. They represent an important subgroup of particulate matter within indoor air and they directly influence microbial air quality (Cox and Wathes, 2020).

More specifically:

Bioaerosols are particles that contain biological material and originate from living organisms or their byproducts. Within bioaerosols, microbial aerosols refer to the fraction composed of viable or non-viable microorganisms and their spores e.g., bacterial cells, fungal spores (Cox and Wathes, 2020).

Microbial air quality focuses on the type, abundance, and behavior of airborne microorganisms in a given environment and it is an important subset of overall indoor air quality.

In agricultural contexts like mushroom houses, bioaerosols ultimately comprise a mix of airborne bacteria and fungi that may originate from substrates, growing biomass, workers, ventilation systems, and outdoor air, contributing both to cultivation outcomes and occupational exposure.

Airborne Microbial Communities: Bacteria vs Fungi

Bioaerosols in indoor environments typically include a diverse collection of microbial taxa, with bacteria and fungi being the most commonly identified components. Studies of indoor air across different settings consistently find both bacterial and fungal communities present, though their relative abundance and dynamics differ (Saridaki et al., 2023).

Bacteria in Air

Airborne bacteria are often numerically dominant among living bioaerosols. Although bacterial cells vary in size (typically 0.5–10 µm), many are small enough to remain suspended as breathable particles (Ewa & Anna, 2024; Prussin & Marr, 2015).

The composition of bacterial aerosols depends on environmental conditions and sources; for example, human occupants, soil particles, and plant materials contribute diverse bacterial species to indoor air (Nazima et al., 2022).

Fungi in Air

Fungal components of bioaerosols include spores and mycelial fragments, which tend to be larger (1–30 µm) than many bacterial cells but are still capable of prolonged suspension.

Fungal spores in indoor air commonly belong to genera like Cladosporium, Aspergillus, Penicillium, Alternaria, and others, many of which have also been documented in agricultural greenhouse and controlled cultivation contexts (Jabeen et al., 2023).

Both bacteria and fungi contribute to the indoor airborne microbial community, but they often differ in sources, environmental drivers, and dynamics. For example, bacteria are influenced heavily by occupancy and activity, whereas fungal spore concentrations often reflect outdoor airborne loads and moisture conditions indoors.

Understanding the distinct ecological behavior of bacteria and fungi is essential when evaluating microbial air quality in a cultivation facility that involves organic substrates and active biological growth.

Bio-aerosol Generation and Dynamics Indoors

Bio-aerosol generation refers to the processes by which microorganisms become airborne from surfaces, materials, or activities within an enclosed environment. In indoor spaces like mushroom cultivation facilities, bioaerosols originate through multiple mechanisms like emissions and activities (Nazaroff, 2014).

Physical Disturbance and Human Activity

Movement, substrate handling, and worker activities can stimulate microbes from surfaces or substrates, hence making them airborne.

Human occupants are also direct sources, shedding bacteria from the skin and respiration, thereby contributing to airborne microbial loads in the facility (Nazima et al., 2022).

Standardized Threshold Limits for Bioaerosols and Their Applicability to Pleurotus ostreatus Facilities in Nigeria

- Lack of universal bioaerosol standards

There are no globally standardized regulatory limits for airborne bacteria and fungi, particularly in agricultural and mushroom cultivation environments.

Bioaerosol thresholds vary by country and are often context-specific, unlike chemical air pollutants with well-defined limits (Cox and Wathes, 2020; Jeong et al, 2022).

- Internationally referenced guideline ranges

Several occupational and indoor air quality guidelines provide defensible benchmark values for evaluating microbial air quality:

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i. Total airborne fungi: ≈500 CFU/m³ commonly cited as an upper guideline for indoor environments (WHO-referenced guidance; Jeong et al., 2022).

ii. Total airborne bacteria: values ranging from 500–1000 CFU/m³ are often used in occupational and public facility assessments (Jeong et al., 2022).

iii. Occupational or high-activity environments may tolerate higher limits (up to 1000–5000 CFU/m³ for total bacteria) depending on exposure duration and susceptibility (EPA-linked European guidance, Fan et al., 2017).

- Examples of national or regional benchmarks

The Korean Ministry of Environment and Korea Disease Control guidelines recommend:

i. <800 CFU/m³ for total airborne bacteria

ii. <500 CFU/m³ for airborne fungi in public and multi-use indoor facilities, particularly where health protection is a concern (KME, 2021).

- Use of international benchmarks in Nigerian studies

Nigeria currently lacks enforceable bioaerosol exposure limits for indoor agricultural or occupational environments.

Nigerian indoor air quality studies frequently adopt European Community Commission (ECC)–style categories for interpretation:

i. <500 CFU/m³: acceptable

ii. 500–2000 CFU/m³: elevated or intermediate contamination

These benchmarks have been applied in laboratory, academic, and healthcare indoor environments across Nigeria (Ikon et al., 2022).

- Relevance to Pleurotus ostreatus cultivation facilities

Oyster mushroom production inherently involves:

i. High relative humidity

ii. Organic substrates

iii. Continuous fungal spore release during fruiting

As a result, baseline airborne microbial counts may be higher than in offices or residential spaces.

Nevertheless, persistent exceedance of guideline ranges (e.g., >500–1000 CFU/m³) may indicate:

i. Increased risk of product contamination

ii. Elevated occupational exposure for workers

iii. Inadequate ventilation or filtration

- Implications for Nigerian mushroom facilities

In the absence of national regulations, applying internationally recognized threshold ranges provides:

i. A defensible framework for interpreting air sampling data

ii. A basis for comparing facilities or production stages

iii. Guidance for implementing mitigation measures (e.g., improved ventilation, targeted filtration)

- Future regulatory and research needs

There is a need for localized Nigerian studies linking:

i. Airborne microbial concentrations

ii. Worker health outcomes

iii. Mushroom yield and contamination rates

Such data would support the development of context-appropriate bioaerosol guidelines for tropical agricultural systems.

Environmental Conditions

Temperature, relative humidity, and ventilation systems influence both the release and persistence of airborne microbes. For instance, higher humidity aids the survival of fungal spores and may increase airborne fungal fractions, while temperature and air movement affect bacterial survival and transport (Jabeen et al., 2023).

Sources

Indoor bioaerosols originate from internal sources (e.g., mushroom substrate, organic dust) and outdoor air intrusion through ventilation, doors, and windows.

Ventilation systems and airflow patterns affect bio-aerosol distribution, with poorly maintained filters or stagnant air increasing microbial persistence.

Once generated, bioaerosols undergo dynamic processes which include:

- Transport by airflow
- Gravitational settling
- Deposition on surfaces
- Removal by ventilation and filtration

These dynamics depend on particle size. Smaller bacterial particles and spore fragments remain airborne longer and are transported more readily. While in contrast, larger particles settle faster but can still contribute to local contamination. Understanding these dynamics is particularly relevant for cultivation facilities: airflow designs, humidity control, and substrate handling practices directly affect how microbes are released and migrated within the airspace.

Determinants of Microbial Air Quality

Microbial air quality in indoor agricultural environments, including Pleurotus ostreatus cultivation facilities, is shaped by a combination of environmental, operational, and biological factors. These determinants influence how airborne bacteria and fungi are introduced, persist, and dispersed within controlled airspaces. Understanding these interacting factors is essential for managing indoor air quality and reducing contamination risks in mushroom production systems (Chawla et al., 2023).

Environmental Factors

Environmental conditions such as temperature, relative humidity, and particulate matter levels significantly affect the concentration and viability of airborne microbes.

Temperature and Humidity

Temperature and relative humidity directly influence microbial survival, reproduction, and aerosol dynamics. Warmer conditions often enhance metabolic activity and the release of microbes into the air, whereas relative humidity affects how long microbes remain viable once airborne (Nasri et al., 2022). High humidity conditions may promote fungal spore release but can also impact the viability of certain bacterial species (Nasri et al., 2022). Relative humidity and temperature interact to shape the microbial load detectable in indoor air (Nasri et al., 2022). These relationships have also been documented in agricultural settings, where increased humidity has been linked to higher airborne microbial concentrations due to increased spore release from substrates or plant surfaces, and temperature modulates microbial stability (Ru et al., 2023).

Particulate Matter and Environmental Contaminants

Particulate matter, especially fine particles, acts as a carrier for microbes and can prolong their residence time in the air. Larger particles readily settle, but fine particulate matter (e.g., PM2.5) can transport microbes over longer distances indoors, increasing exposure risks (Ru et al., 2023). While this mechanism has been demonstrated in broader environmental studies, it is relevant to cultivation houses where dust, substrate particulates, and bioaerosols coexist.

Overall, temperature, humidity, and particulate dynamics jointly influence how microbes are emitted, suspended, and transported within indoor environments, including agricultural airspaces.

Facility Operational Factors

Operational facility factors strongly influence microbial air quality by controlling how airborne microorganisms are diluted, distributed, and removed indoors. Air exchange rates, commonly expressed as air changes per hour (ACH), determine the frequency of air replacement and are critical for reducing airborne bacterial and fungal concentrations through dilution and removal (Sankurantripati, 2024). Mechanical systems such as fans and Heating, Ventilation, and Air Conditioning (HVAC) units further shape microbial distribution by regulating airflow and filtration; well-designed and maintained systems minimize stagnation and localized contamination (Hassan et al., 2021). Additionally, human activity and operational schedules can stimulate microbes, especially when ventilation is insufficient, leading to elevated bioaerosol levels (Nasri et al., 2022).

Air Exchange Systems

Ventilation Systems.

Studies assessing built environments have shown that proper mechanical ventilation with filtration can reduce airborne microbial concentrations, whereas poorly designed or absent ventilation can lead to higher accumulation of microorganisms indoors (Hassan et al., 2021). Adequate air exchange rates help dilute bioaerosols and can mitigate the effects of microbial emissions from substrates and workers.

Airflow design and patterns.

Air movement patterns influence where bioaerosols accumulate. Stagnant zones with little airflow allow microbes to settle or persist, whereas directed airflow can help remove microbial particles from sensitive cultivation areas. In agricultural facilities, air currents generated by fans or forced ventilation may either dilute microbial concentrations or , if poorly configured, redistribute contaminants across the facility.

Thus, ventilation efficacy and airflow dynamics are crucial in determining whether microbial air quality is maintained at safe levels or degraded by internal emissions and external intrusions.

Mechanical Systems and Microbial Air Quality in Indoor Cultivation

Fans and Air Circulation

Mechanical fans create air movement that influences microbial transport within enclosed facilities. By promoting consistent circulation, fans help prevent stagnation zones where bioaerosols settle and accumulate. Studies show that poorly circulated air can lead to localized hotspots of microorganisms, whereas well-distributed airflow encourages dispersion and removal of airborne bacteria and fungi (Hassan et al., 2022)

HVAC Systems and Filtration

Heating, ventilation, and air-conditioning (HVAC) systems shape indoor air quality by controlling both airflow and filtration. Filters integrated into HVAC units capture particulate matter and airborne microbes, reducing the overall concentration of bacteria and fungal spores in the air (Luongo et al., 2016). Regular maintenance, including cleaning or replacing filters, is critical, as clogged or neglected filters can become sources of microbial release, undermining air quality efforts by allowing microbial growth and re-aerosolizing.

Impact of System Design

The configuration and maintenance of mechanical systems determine their effectiveness. The use of systems that provide balanced circulation, avoidance of dead zones, and incorporation of High-efficiency Particulate Air (HEPA) filters have been associated with lower airborne microbial loads in controlled indoor environments, by enhancing particle removal and minimizing microbial persistence (Luongo et al., 2016).

Biological and Operational Sources

Within a cultivation facility, the most direct sources of airborne microbes are biological activities and operational practices associated with mushroom production.

Substrate and Biomass Emissions

Organic substrates used in P. ostreatus cultivation such as straw, sawdust, or agricultural waste, harbor microbial communities. Handling, turning, and processing these materials liberates spores and bacterial cells into the air, contributing to the facility's bio-aerosol load. Similarly, the mycelial growth and fruiting phases of mushrooms naturally release spores that become suspended in the air. Although specific studies on oyster mushroom houses are limited, analogous findings in greenhouse cultivation environments show that plant and substrate surfaces are significant internal sources of airborne bacteria and fungi in the cultivation facility (Kozdrój et al., 2024).

Human Activity and Occupancy

Activities such as substrate preparation, bagging, harvesting, and worker movement stir up particles and microbes from surfaces and substrates, increasing airborne microbial counts, as earlier stated. Human occupancy also contributes to airborne bacteria, as occupants shed skin cells and respiratory microbes, a pattern observed in indoor environments broadly (Ahmed et al., 2021). Even limited human traffic within a mushroom house can influence airborne microbial community composition.

Operational practices

How often substrates are watered or irrigated, the frequency of sanitation procedures, and the schedule of substrate turning can all alter the stimulation and release of microbes. High humidity practices intended to optimize mushroom growth may unintentionally increase the aerosolization of microbes. Similarly, inadequate sanitation or irregular filter maintenance in ventilation systems fosters microbe persistence and accumulation.

Outdoor and Facility Context

Bioaerosols from the external environment also influence indoor microbial air quality. Outdoor airborne microbial communities vary with local vegetation, soil, and meteorological conditions, and outdoor microbes may enter via ventilation or open doors. Without proper filtration, outdoor microbes, including fungal spores and environmental bacteria, can contribute to indoor microbial loads.

Water and Irrigation Practices as a Determinant of Microbial Air Quality

Water and irrigation practices can influence microbial air quality by acting as sources of bioaerosols and by altering environmental humidity, both of which affect airborne microbial persistence and dispersal. When irrigation systems produce water spraying or misting, droplets can become carriers for microorganisms present in the water, contributing to airborne microbial loads if the water contains microbial contaminants (Adiyani et al., 2025). Microorganisms introduced through irrigation water, especially when sourced from non-potable or reclaimed supplies, can harbor bacteria and fungi that affect both soil and adjacent air microbial communities (Guo et al., 2022). Additionally, irrigation practices that increase surface moisture can enhance the aerosolization of microorganisms from wet surfaces and substrates; moisture facilitates the release of microbes into the air, particularly under air currents or mechanical disturbance. Consequently, water quality and irrigation method are operational considerations that can indirectly shape the composition and concentration of bioaerosols in and around cultivation facilities.

Table 1: Hierarchical Framework of Determinants Influencing Microbial Air Quality in Pleurotus ostreatus Cultivation Facilities

S/N	Hierarchy Level	Determinant Category	Specific Determinant	Influence on Microbial Air Quality Key	Implications for Nigerian Mushroom Facilities	Reference
1.	Level 1 (Primary Drivers)	Environmental Factors	Temperature	Regulates microbial metabolism, survival, and aerosol stability; higher temperatures can increase microbial activity and release into air.	High ambient tropical temperatures require controlled ventilation to prevent microbial proliferation.	Nasri et al., 2022
			Relative Humidity (RH)	High RH promotes fungal spore release and prolongs airborne microbial viability; interacts with temperature to shape overall microbial load.	Humidity levels (70–90%) used for mushroom growth can unintentionally elevate airborne spores.	Nasri et al., 2022; Ru et al., 2023

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			Particulate Matter (PM2.5, dust)	Fine particles act as carriers for microbes, increasing suspension time and indoor transport distance.	Dust from substrates (sawdust, rice straw) increases bioaerosol persistence.	Ru et al., 2023
2.	Level 2 (System Controls)	Facility Operational Factors	Air Exchange Rate (ACH)	Higher ACH dilutes and removes airborne microbes, reducing bacterial and fungal concentrations.	Many Nigerian facilities rely on natural ventilation, increasing contamination risk.	Sankurantripati, 2024
			Ventilation Design	Proper mechanical ventilation reduces microbial accumulation; poor design leads to bioaerosol buildup.	Poorly designed openings can introduce outdoor spores without filtration.	Hassan et al., 2021
			Airflow Patterns	Directed airflow removes microbes, while stagnant zones promote persistence and localized contamination.	Low-cost fan placement is critical to avoid dead zones in grow rooms.	Hassan et al., 2021
3.	Level 3 (Mechanical Modifiers)	Mechanical Systems	Fans and Air Circulation	Prevent stagnation, redistribute bioaerosols, and reduce microbial hotspots when well configured.	Stand-alone fans are common substitutes for HVAC systems.	Hassan et al., 2022
			HVAC Systems & Filtration	Filtration captures airborne microbes; poorly	Limited HVAC adoption makes filtration a key intervention gap.	Luongo et al., 2016

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				maintained systems may re-aerosolize contaminants.		
			HEPA & System Design	Balanced circulation and HEPA filters significantly reduce airborne microbial loads.	Often absent due to cost; targeted use in spawning rooms is recommended.	Luongo et al., 2016
4.	Level 4 (Direct Internal Sources)	Biological & Operational Sources	Substrate & Biomass Handling	Organic substrates and mushroom growth release spores and bacteria during handling and fruiting.	Manual substrate mixing and bagging increase exposure.	Kozdrój et al., 2024
			Human Activity & Occupancy	Worker movement resuspends microbes; humans shed skin- and respiratory-associated bacteria.	Continuous harvesting cycles amplify bioaerosol levels.	Ahmed et al., 2021
			Operational Practices	Irrigation, sanitation frequency, and substrate turning influence microbial stimulation and release.	Limited personal protective equipment use elevates occupational exposure.	Nasri et al., 2022
5.	Level 5 (External Modifiers)	Outdoor & Water Inputs	Outdoor Bioaerosols	External microbes enter via ventilation and doors, influencing indoor microbial composition.	Proximity to farms, waste dumps, or vegetation raises spore influx.	Chawla et al., 2023
			Irrigation Water Quality	Spraying and misting aerosolize waterborne microbes; non-	Non-potable water sources may introduce	Adiyani et al., 2025; Guo et al., 2022

				potable water increases contamination risk.	additional contaminants.	

Impacts of Poor Air Quality on Cultivation facility Outcomes

Contaminant Competition with Pleurotus spp.

Airborne and substrate-borne microbial contaminants compete with Pleurotus ostreatus for nutrients and space, directly impacting fungal growth. Green mold pathogens, especially Trichoderma species, are among the most common competitors in oyster mushroom cultivation and can rapidly colonize substrates, inhibiting Pleurotus mycelial expansion (Ajis et al., 2024). These competitors produce enzymes and volatile metabolites that degrade substrate components and alter its microbial ecology, reducing the resources available for mushroom mycelium (Ponnusamy et al., 2022). Competitive interactions can lead to slower colonization rates, reduced biomass accumulation, and impaired development of fruiting bodies, ultimately decreasing the biological efficiency of cultivation systems. High levels of competitive microbes also increase the difficulty of achieving dominance by Pleurotus in mixed microbial communities, especially when air quality issues facilitate spore and microbial dissemination throughout the facility (Ajis et al., 2024).

Disease Risk and Contamination (e.g., Green Mold)

Poor microbial air quality increases the risk of disease and contamination in Pleurotus cultivation, particularly by airborne pathogens. Green mold disease caused by Trichoderma spp. is a significant threat to oyster mushroom production, often gaining entry through contaminated air, water, and substrate handling practices (Ajis et al., 2024; Ponnusamy et al., 2022). Once established, these pathogens can rapidly overgrow cultivated mycelium due to their faster growth rates and robust enzymatic activity, leading to symptomatic green sporulation and substrate decay (Ajis et al., 2024). Infected bags show visible mold patches, reducing crop uniformity and often resulting in total crop failure if not controlled. Effective air quality management is therefore critical to minimize airborne inoculum and reduce the likelihood of contamination events (Lombardi, 2023; Ajis et al., 2024).

Effects on Yield and Mushroom Quality

Airborne microbial contamination and disease not only decrease yield but also compromise the quality of Pleurotus ostreatus products. Green mold and other pathogens reduce biological efficiency and fruit body development, resulting in lower fresh weight and inferior physical quality of harvested mushrooms (Ajis et al., 2024; Lombardi, 2023). Furthermore, contaminated air and poor microbial management can lead to higher post-harvest microbial counts, accelerating spoilage and shortening shelf life (Abou Fayssal et al., 2023). Microbial spoilage influences texture, flavor, and safety of harvested fruiting bodies, potentially increasing the presence of off-odors, discoloration, and decay organisms. Therefore, maintaining high air quality is essential not only for maximizing yields but also for ensuring marketable and safe products for consumers (Abou Fayssal et al., 2023).

Respiratory Health Risks of Occupational Exposure to Bioaerosols in Agricultural Settings

Occupational exposure to bioaerosols in agricultural environments is linked to a spectrum of adverse respiratory health outcomes among workers. This is particularly relevant in mushroom cultivation facilities, where high humidity, substrate handling, and continuous fungal spore release contribute to elevated airborne microbial loads. Epidemiological and clinical studies indicate that chronic or repeated inhalation of organic dusts, fungi, and bacteria can lead to both acute and chronic respiratory conditions. Commonly reported outcomes include cough, wheezing, bronchitis, asthma, and hypersensitivity pneumonitis, resulting from inflammatory and immunological responses to bioaerosol components (Nordgren & Bailey, 2016).

Specifically, studies of farm workers exposed to fungal bioaerosols have documented decreased lung function and elevated prevalence of respiratory symptoms. For instance, research on mushroom and vegetable farm workers found that higher fungal concentrations negatively affected lung function measures, underscoring the occupational hazard posed by prolonged exposure without adequate respiratory protection (Tarigan et al., 2017). Additionally, agricultural workers generally experience elevated rates of chronic respiratory diseases such as chronic obstructive pulmonary disease (COPD) and bronchitis, which have been attributed to repeated bioaerosol inhalation and co-exposures to organic and inorganic particles (Nordgren & Bailey, 2016).

Acute syndromes such as Organic Dust Toxic Syndrome (ODTS) — characterized by fever, cough, dyspnea, and malaise following heavy exposure to organic particulate matter — are also recognized among farmers, grain handlers, and mushroom workers exposed to dense bioaerosols (Douglas et al., 2018). Such conditions highlight the importance of exposure assessment, proper ventilation, and the use of effective respiratory personal protective equipment (PPE) in reducing risk.

Collectively, these findings support the inclusion of a public health narrative in discussions of microbial air quality management, emphasizing the direct link between occupational bioaerosol exposure and respiratory health risk in agricultural production settings.

Synthesis & Recommendations

Summary of Key Determinants

The determinants of microbial air quality in indoor cultivation environments are multi-faceted. Environmental factors, such as humidity and temperature, influence microbial survival and aerosolization, and ventilation performance shapes airborne microbial concentrations (World Health Organization, 2010; Mengyao et al., 2025). Operational factors, including air exchange rates and HVAC system design, regulate the dilution and removal of microbes (Dai et al., 2021). Biological sources, such as substrate emissions and worker activity, contribute to microbial loads, while external sources (outdoor air, dust) further affect indoor bioaerosol profiles (Ghosh et al., 2015). Together, these determinants interact dynamically; improved ventilation and filtration can mitigate the impacts of internal emissions (Dai et al., 2021; Li et al., 2007). Understanding these interconnected determinants is essential for effective cultivation air quality management.

Best Practices for Maintaining Optimal Air Quality

Maintaining optimal air quality in cultivation facilities requires a holistic approach combining ventilation, filtration, moisture control, and source management. Adequate ventilation, whether natural, mechanical, or hybrid, is critical for diluting and removing airborne microbes (NIH Bookshelf, 2010). Filtration with high-efficiency filters (e.g., HEPA) effectively reduces bioaerosol concentrations in recirculated air (Dai et al., 2021). Controlling moisture and humidity limits conditions favorable for fungal growth and spore release (NIH Bookshelf, 2010). Operational practices such as regular maintenance of ventilation and filtration systems, scheduled cleaning of substrate handling areas, and monitoring environmental parameters help sustain air quality. Additionally, minimizing unnecessary worker traffic during sensitive phases can reduce microbial stimulation.

Real-Time and “Smart” Monitoring Technologies in Managing Microbial Air Quality

Emerging smart monitoring technologies such as real-time bioaerosol sensors and biosensors offer promising advances for managing airborne microbial contamination in controlled agricultural environments. Traditional microbiological air sampling (e.g., impaction and culture-based methods) provides accurate counts but suffers from long turnaround times and cannot capture temporal variations in bioaerosol dynamics. In contrast, real-time detection systems based on optical and fluorescence spectroscopy, holography, and advanced sensor networks are capable of detecting and differentiating bioaerosol particles such as bacteria, fungal spores, and plant pollen with fine temporal resolution. For example, fluorescence-based instruments can detect bioaerosol particles by exploiting specific bio molecular signatures, making it possible to observe daily fluctuations in airborne microbial load caused by human activity or environmental changes (Lancia et al., 2023; Huang et al., 2017).

Real-time monitoring has been successfully applied in indoor air quality research to identify peak bioaerosol concentrations and to evaluate the effectiveness of mitigation measures such as ventilation and air purification systems. These technologies enable continuous surveillance and rapid response to contamination events, which could significantly improve bioaerosol management in mushroom cultivation houses where conditions (e.g., high humidity) favor spore release. Additionally, recent research integrates machine learning models with sensor data to estimate microbial concentrations, offering predictive capabilities that enhance proactive facility control (Huang et al., 2017).

Furthermore, broadband integrated bioaerosol sensors and emerging nanotechnology-based platforms (e.g., carbon nanotube field-effect transistor biosensors) are being developed for in situ continuous monitoring of specific microbial taxa. Such systems hold potential for low-cost deployment and scalability in operational settings, including resource-limited environments (Huang et al., 2017).

Incorporating these technologies into facility air quality management can shift operational practices from periodic sampling to continuous surveillance, enabling rapid mitigation decisions and improving worker safety and crop health.

Knowledge Gaps and Future Research Directions

Despite progress, several knowledge gaps persist. Quantitative data detailing microbial thresholds linked to specific cultivation outcomes remain limited (Loveniers et al., 2024). There is a lack of standardized guidelines for microbial air quality specific to agricultural environments, including mushroom cultivation facilities (Loveniers et al., 2024). Studies quantifying the effectiveness of specific interventions (e.g., UV-C irradiation, optimized HVAC configurations) in reducing airborne microbes in cultivation settings are sparse. Future research should develop risk-based thresholds, evaluate real-time monitoring technologies, and examine cost-effective ventilation and filtration strategies tailored to mushroom cultivation contexts. Longitudinal studies linking air quality metrics to yield and contamination rates would strengthen evidence for best practices.

CONCLUSION

Main Takeaways

This literature review establishes that microbial air quality in Pleurotus ostreatus cultivation facilities is governed by the interaction of environmental, operational, biological, and external factors. Temperature and relative humidity strongly influence microbial survival and aerosolization, while airflow and ventilation determine microbial dispersion and persistence within cultivation spaces. Operational facility factors, such as air exchange rates, mechanical ventilation systems, and maintenance practices, play a central role in diluting or concentrating airborne microorganisms. Biological sources, including mushroom spore release, substrate emissions, and worker activity, represent continuous internal contributors to bioaerosol loads. External inputs from surrounding environments and water or irrigation practices further modify indoor microbial conditions. Collectively, these determinants directly affect contamination risks, disease development, yield stability, and mushroom quality, highlighting the importance of air quality management in oyster mushroom production.

Implications for Cultivation Management

For effective Pleurotus ostreatus cultivation, air quality management should be integrated into routine production planning. Cultivation managers should prioritize controlled humidity and temperature, supported by efficient ventilation and balanced airflow to minimize microbial accumulation. Proper design, operation, and maintenance of mechanical systems, particularly fans, filters, and air circulation units, are essential for reducing bioaerosol hotspots. Attention to substrate handling, sanitation schedules, and worker movement can further limit bioaerosols release. Additionally, ensuring clean water sources and appropriate irrigation methods helps prevent microbial introduction through aerosolized moisture. Implementing these measures can reduce contamination pressure, enhance yield consistency, and improve overall mushroom quality, contributing to more sustainable and economically viable oyster mushroom cultivation systems.

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