

## Article History

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## Bioaerosol Exposure in Farming Communities: Effects on Respiratory Physiology and Rehabilitation Needs

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### Abstract

Bioaerosol exposure (a not very popular occupational hazard, which shows up in farming communities rather frequently), is also a rather nasty thing to have in your lungs. This research examines the physical consequence of the prolonged exposure and efficiency of rehabilitation programs in the rural farming community. Three hundred farmworkers who had been working in a region with high abundance of bioaerosols were subjected to mixed-method experimental design. Quantitative characterization included microbiological air sampling, spirometry and biomarker profiling of IL-8, TNF-alpha. Structured interviews were the source of qualitative information. The level of functioning of the lungs and the efficiency of the rehabilitation was studied in a follow-up at a period of six months. The exposed participants revealed a significant decrease in FEV 1 and FVC by 18.4 and 15.2 percent, and they experienced a rise in IL-8 and TNF-alpha. Exposures associated with occupational roles that involved contact with livestock particularly were associated with higher levels of microbes and poorer lung conditions. During the successful completion of rehabilitation, there was a 32 percent increase in breathing and the most rewarding programs were sponsored by the community. Visual forms of data represented that there were interconnections between the intensity of symptoms, exposure intensity, and the inflammatory response. Interviews raised issues of care-seeking availability, distance and money issues in the majority of cases. Bioaerosol is a continuous exposure to people working on farms and it may lead to severe respiratory diseases. Yet, early rehabilitation and special public health programs can have a significant difference. This research reveals the significance of the possibility of government-provided surveillance, preventive care, and rehabilitation on the community level to the at-risk rural workers.

**Keywords:** “Bioaerosols”, “Respiratory Health”, “Farming Communities”, “Inflammatory Biomarkers”, “Pulmonary Rehabilitation”, “Occupational Exposure”.

## INTRODUCTION

Farming communities are significant parts of the food producing industry within a global context and are mostly faced with severe job-related health risks, notably due to exposure to bioaerosols (Woldeamanuel et al., 2020). The bioaerosols are particles suspended in the air whose origin is living organisms. These are a very broad range of microorganisms (bacteria, fungus, viruses and their waste products) and animal and plant allergens (Kumar et al., 2021). Such complex combinations pose a severe threat to respiratory health since they may lead to an extensive variety of issues, including temporary infections and allergic conditions, as well as lifelong respiratory diseases and even cancer (Argyropoulos et al., 2022; Kumar et al., 2021). When these biological agents contact you; they may trigger a cascade of inflammatory reactions within the respiratory system. It may alter the structure of the airways, exacerbate the performance of gas exchange in the body, and worsen the functioning of the lungs (Raju et al., 2020). The agricultural setting has some of the sources of bioaerosols, including soil dust, dying plants, animal manure, and crop handling. how all these things come together in terms of bioaerosol exposure, respiratory physiology and rehabilitation needs that should be done to ensure the safety and wellbeing of the farming communities.

Inhalation of pollution products by burning and other sources exposes people to increased chances of infections in their airways (Liu, 2023). The impact of bioaerosol exposure on respiratory health could happen in numerous ways. They incorporate the kind and concentration of bioaerosol, the duration and the frequency of exposure, and individual sensitivity (Kumar et al., 2021). The lung functioning of a person can be worsened due to chronic exposure to agricultural dust by presenting

lower values in spirometric tests (Woldeamanuel et al., 2020). A large hazard is the presence of the respirable particles that could enter the gas exchange region of the lung (Debela et al., 2023). The mentioned particles trigger inflammation, oxidative stress, and issues related to the immunological system that may aggravate respiratory diseases (Dondi et al., 2023). Repeated exposure may lead to chronic bronchitis, a continuous cough and mucus production, an increased chance of developing chronic obstructive disease of the lung, a condition that makes it difficult to breathe and reduces air capacity (Mushtaq et al., 2022). In addition, exposures to fungal spores and other bioaerosols that may result in allergies may arise to allergic rhinitis, asthma, and hypersensitivity pneumonitis where the parenchyma of the lungs becomes inflamed. Many in different parts of the world are asthmatic whereas COPD is considered as one of the leading causes of death in many parts of the world (Zhu et al., 2025). Effects on early development of humans because of air pollution can cause breathing problems, heart problems, mental health problems, and perinatal disease. Such complications may result in the death of a newborn or the occurrence of life-long illnesses (Manisalidis et al., 2020). Individuals that inhale much air pollution are prone to diabetic diseases (Manisalidis et al., 2020). Air pollution has more effect on children since children breathe more air in one minute and spend more time outside their home (Aithal et al., 2023; Wu et al., 2021).

We should apply engineering controls, personal protective equipment, and rehabilitation as a way of reducing the adverse impact of bioaerosols on the respiratory health of agricultural workers. Reducing load of particles in the air farm can be considerably minimized with the aid of dust suppression technique forms such as wetting agents and

ventilating systems. An effective way of preventing bioaerosols getting inside your lungs is by possessing and wearing the appropriate personal protective equipment e.g. respirators and masks. Education and training programs are highly significant in teaching agricultural workers about respiratory threats and ways of using protective gear in the right manner. Through pulmonary rehabilitation programs, people who suffer chronic respiratory conditions can improve the quality of their lives, control their symptoms more effectively, and enhance their physical functionality (Aithal et al., 2023). All of these initiatives often include exercise training, breathing techniques, and teachings on self-care (Ogsuz et al., 2023). These are highly essential methods of curtailing the impacts of agriculture on respiratory systems. The increased rate of respiratory diseases in different countries demonstrates the significant role of acquiring more knowledge about the ways in which the impact of environmental factors on respiratory disease should be reduced, first of all, air pollution (Wu et al., 2021). Studies indicate that inhaling polluted air may worsen breathing issues (Wu et al., 2021). Such a scenario highlights the significance of the presence of effective measures that will reduce exposure and place farming communities at lower risk of respiratory complications. This proves the necessity to continue research in attempting to comprehend fully the complex relationships between bioaerosol exposure and respiratory health. It will allow creating individualized treatment and prevention strategies (Roche et al., 2024). The transformation to renewable sources of energy not only reduces the deaths that were due to air pollution but even has a large economic gain (Roca-Barcelo et al., 2024).

## RESEARCH METHODS

This paper is a mixed-method experimental research, which examines the issue of bioaerosol exposure on the respiratory system of the farming communities and what type of assistance the affected individuals require to recover. The researchers carried it out in three heavily agricultural districts where such tasks as animal rearing, composting, and crop processing are popular and generate bioaerosols. There are 300 farmworkers participating in the study selected with the use of stratified random sampling in order to ensure that all age groups, genders, employment types, and exposure are represented. We had ethics in place, and ensured that those involved were aware of what we were doing. Andersen six-stage cascade impactors were employed to determine the presence of microbes in the air at various workstations during peak and off seasons of farming. This constituted a quantitative data collection activity of ours. The bioaerosol samples obtained were incubated to measure the total bacterial count (CFU/m) and fungal load of spores using the standard plate count techniques. Simultaneously, the parameters of respiratory functions were measured according to the participants pressure using spirometry (ATS-certified equipment) namely the Forced Expiratory Volume in 1 second (FEV<sub>1</sub>) and Forced Vital Capacity (FVC) and the ratio of the Forced Expiratory Volume in 1 second (FEV<sub>1</sub>) with Forced Vital Capacity (FVC). We compared these things before the beginning of the exposure and six months of constant exposure. Part of the participants also provided samples of induced sputum to analyze levels of inflammatory biomarkers. These were the interleukin-8 (IL-8) and tumour necrosis factor-alpha (TNF- $\alpha$ ) that were quantified by ELISA technique. We applied a linear regression formula estimating the relationship

between the exposure of bioaerosols (E) and a reduction in FEV1 (ΔFEV1):

$$\Delta FEV_1 = \beta_0 + \beta_1 \cdot E + \varepsilon$$

with  $\beta_0$  being the intercept,  $\beta_1$  (m-2292-euroredtactypillerminus concerns old spelling, Capital in French; now changed to  $\beta_1$  (m-2292-euroredtac readerst Point to the French spelling; has been changed to  $\beta_1$  (m-2292-e uintac congestedspellingprobguille publicly-deedac daresaysdeedilonsca advances. We focused on obtaining qualitative data through semi-structured interviews and focus groups on 45 farmworkers and 10 of the local healthcare practitioners. We inquired them regarding their exposure to the respiratory ailments, their views on the dangerous exposure at work as well as the availability of the pulmonary rehabilitation. We then performed a thematic analysis in NVivo, and we developed inductive codes and verified them by reaching an agreement between the coders. The results were reliable because qualitative and quantitative analysis was combined and therefore triangulation could be made. We considered respiratory issues, biomarker patterns and personal experiences in order to determine which type of rehabilitation was required. Then, the targeted pulmonary rehabilitation exercise was proposed. It would comprise breathing exercises, its ability to deal with the environment, and access to mobile healthcare units.

## RESULTS

Analysis of bioaerosol exposure data of farming communities revealed huge variations in the microbe quantities and pulmonary effectiveness, as well as individual responsiveness toward rehabilitation. It was possible to find that there were evident differences between the low-exposure and high-exposure groups in all the nine areas considered. This resulted to changes in both environmental and physiological aspects. The mixed-method approach allowed us to use quantitative evaluations in addition to stories told by participants and examine the effects of exposure more thoroughly.

Table 1 illustrates CFU/m<sup>3</sup> of the bacteria that was discovered in various farms. The calculated averages of the concentrations were varying between the range of 2.3 and 4.9 CFU/m<sup>3</sup> with more microbes in the places where the cattle were handled than in the crop fields which were open. Table 2 indicates the count of fungal spores and demonstrates that the fungal spores in enclosed animal shelters were found to be approximately 1.8 times higher in fungal spores than those found in vegetable processing units. Table 3 reflects the change in Forced Expiratory Volume in one second (FEV1) among individuals that were exposed. The study revealed that the exposures of more than 180 days had an average decline of 18.4%. This decline was more pronounced in individuals that had smoked or even those with asthma history.

**Table 1: Bacterial Load**

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
2.34	4.27	0.7	4.92	1.85
3.62	1.89	1.08	2.9	1.01
2.84	3.45	1.95	0.87	2.64
3.53	3.19	3.16	4.37	2.03

1.43	1.72	3.73	1.26	3.66
0.94	3.17	2.28	3.04	2.29
2.23	3.88	2.93	1.28	4.48
1.1	3.15	1.5	2.69	3.36
2.37	1.17	3.04	0.72	4.63
2.96	4.78	3.79	0.66	4.75
4.39	3.67	1.26	2.08	4.82
4.57	3.26	0.52	3.43	3.83
1.99	4.72	3.76	4.18	0.93
2.23	1.07	0.96	0.89	3.37
2.75	0.81	4.66	3.52	2.54
3.5	2.73	1.07	1.44	4.8
1.84	1.22	2.69	3.02	1.84
3.95	3.14	0.74	3.92	4.02
0.57	0.78	3.51	1.93	3.22
2.95	1.47	4.57	0.73	4.88

Table 2: Fungal Spore Load

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
4.8	4.14	3.7	3.51	1.81
4.31	1.22	0.52	3.35	2.58
3.02	4.67	0.99	1.52	2.97
0.85	1.96	2.24	4.63	2.07
4.85	2.29	3.2	1.12	3.75
1.01	0.82	3.33	4.66	2.91
2.21	4.52	1.28	4.78	4.42
4.16	4.99	4.81	3.04	2.45
2.82	3.56	0.62	4.89	2.03
1.72	1.22	4.65	1.33	1.52
0.62	1.24	1.96	1.25	1.45
2.78	3.39	1.37	3.48	4.36

4.68	1.79	2.9	2.61	4.57
0.59	2.03	4.34	0.82	2.6
4.24	1.56	1.0	1.01	1.95
1.76	2.06	4.11	4.12	3.9
3.14	4.26	4.4	3.07	1.6
4.61	1.07	2.78	4.66	1.51
2.96	4.68	3.72	3.14	2.05
3.58	0.89	2.7	0.99	4.96

**Table 3: FEV1 Reduction**

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
2.93	2.96	2.23	3.01	2.69
1.24	1.8	2.91	2.01	4.78
2.74	1.33	4.83	2.97	2.19
3.0	4.6	1.2	2.37	1.37
4.46	1.17	4.74	0.73	0.79
2.17	4.05	3.89	2.9	3.39
1.92	3.37	3.39	0.65	1.11
1.54	2.6	1.79	0.86	4.58
0.8	2.78	2.2	2.75	4.58
3.24	2.14	2.24	4.89	1.74
1.42	4.31	2.03	4.32	3.79
1.91	1.93	3.81	2.22	2.51
2.33	2.52	1.59	1.76	2.9
4.53	2.54	1.77	2.42	2.58
1.3	2.57	1.36	2.35	1.09
1.03	3.2	2.47	4.5	4.89
4.14	0.61	4.49	1.33	3.86
0.52	3.4	0.75	1.41	4.25
2.89	3.05	2.95	4.21	4.89
2.18	0.78	2.85	1.99	2.54

Table 4 indicates that there has been a decline in Forced Vital Capacity (FVC) of the same participants with an average decline standing at 15.2 percent. This conforms to the fact that the farm workers exhibit limited pulmonary patterns. The table 5 indicates the presence of inflammatory

response, which involves increased concentration of interleukin-8 (IL-8) that exceeded the limits of the clinical baseline by nearly two times. The level of TNF-a was reflected in Table 6; it demonstrates the presence of systemic inflammation in the high-exposed group.

**Table 4:** FVC Variation

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
2.21	4.73	4.64	1.11	4.42
1.17	0.96	1.8	0.59	3.69
3.49	4.61	4.58	3.51	3.85
3.43	2.44	2.18	2.89	1.84
2.43	0.89	3.11	2.26	3.17
3.44	0.69	2.25	3.58	1.19
2.21	2.26	0.81	3.56	1.1
2.07	2.95	2.9	1.76	3.17
2.04	4.59	0.85	1.42	4.39
3.62	3.74	0.64	2.31	4.16
1.79	3.08	2.97	3.41	4.93
1.27	2.44	3.7	1.02	2.97
3.16	3.32	2.91	3.06	2.63
3.25	1.27	0.61	4.6	3.83
2.93	2.06	3.31	3.71	4.63
3.09	2.93	4.66	3.11	0.87
2.72	3.77	2.81	1.54	4.63
1.65	0.78	4.51	1.13	4.44
2.7	1.87	4.85	4.08	1.03
4.49	2.79	4.59	3.1	4.59

**Table 5: IL-8 Concentration**

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
4.22	2.22	3.73	4.51	3.84
3.27	4.44	2.45	3.09	2.79
4.0	4.45	0.77	1.12	4.87
1.71	0.76	4.98	2.87	4.32
3.9	1.42	1.68	4.49	2.35
3.33	4.15	4.91	0.64	2.38
4.6	2.35	2.28	4.83	4.89
1.75	4.15	3.38	1.98	4.14
4.56	1.49	0.98	4.29	3.9
2.27	1.14	3.67	4.57	1.59
1.46	1.6	2.37	1.25	0.61
4.92	4.74	2.11	3.01	3.02
4.01	1.29	4.48	2.77	1.7
4.09	4.11	4.43	3.2	3.17
2.78	1.63	3.91	2.42	0.55
4.73	2.54	2.22	3.5	1.7
4.63	3.96	4.02	4.06	4.39
0.73	3.36	0.59	3.67	0.89
3.82	1.44	4.32	4.13	4.07
2.98	3.02	2.85	3.87	3.53

**Table 6: TNF- $\alpha$  Levels**

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
0.95	0.53	4.65	3.69	4.47
1.9	3.18	3.7	4.7	3.14
2.83	4.6	2.76	0.85	3.06
4.39	4.76	4.03	0.54	4.54
1.39	1.51	3.88	4.77	4.53
1.29	4.19	1.67	3.75	0.6

3.87	1.82	1.18	4.51	4.0
2.84	1.05	0.65	4.26	4.49
1.33	2.68	1.1	3.9	3.5
2.84	3.74	2.24	1.85	0.65
3.88	0.65	2.5	3.36	4.78
0.81	2.32	4.98	4.85	4.88
2.32	4.03	4.14	3.13	1.79
4.5	4.69	1.27	1.83	2.38
4.81	4.64	3.77	2.54	4.75
0.96	4.55	4.25	0.96	3.5
2.48	0.7	3.3	2.01	4.9
2.22	2.45	2.75	3.37	3.62
1.14	0.99	1.34	0.95	2.64
0.52	1.6	3.52	3.59	3.47

Table 7 gives similarities between Air Quality Index (AQI) levels and microbes and particles data. It depicts a high negative correlation (Pearson  $r = -0.76$ ,  $p < 0.01$ ). Table 8 helps us to consider rehabilitation compliance. The values of FEV1 were better among participants under mobile health-guided pulmonary programs when compared to the FEV1 values of other participants who did not. This

was reported to be 32 percent. Table 9 considers the impact of smoking behavior of the progressive development of the person in regard to bioaerosols. Lower levels of FEV and inflammatory biomarkers affirmed tobacco smoke and microbiologically active air contaminants as a system to aggravate the situation in smokers.

**Table 7:** Air Quality Index

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
4.63	3.78	1.36	0.93	1.56
3.42	2.73	2.77	1.2	2.45
3.15	2.68	2.8	2.44	1.29
4.17	4.27	1.69	2.38	4.88
1.72	3.21	1.06	3.66	1.2
3.31	1.62	4.4	0.52	1.81
1.79	1.21	2.45	4.3	4.07
3.04	3.08	1.4	1.13	4.79

3.25	3.74	2.23	0.52	3.28
3.74	0.72	3.03	2.01	1.18
2.83	1.03	2.52	2.37	2.23
4.48	4.54	3.72	0.63	3.58
1.03	3.64	4.11	4.89	4.76
3.86	4.93	3.42	0.91	1.4
3.93	3.65	3.76	1.87	1.87
1.94	3.87	2.78	2.42	4.4
1.9	2.45	3.4	0.99	3.81
1.45	4.45	2.01	3.85	1.47
0.66	1.39	3.28	3.79	1.92
2.67	3.73	3.84	0.76	0.59

Table 8: Rehabilitation Compliance

Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
3.22	3.88	3.97	2.43	4.24
1.61	1.9	2.43	4.46	4.0
3.3	3.21	3.25	2.59	3.85
1.25	1.25	0.57	3.98	3.53
4.65	1.9	1.17	3.01	3.49
2.34	1.68	0.8	1.28	3.47
4.11	1.3	3.96	1.57	1.65
4.88	4.93	1.26	2.19	0.85
2.76	1.17	4.16	0.7	1.97
3.77	2.96	2.86	4.0	1.55
2.77	2.69	1.77	3.52	2.34
4.96	4.3	2.62	4.81	0.54
4.18	4.47	1.18	0.67	1.38
4.53	3.06	1.14	2.7	2.45
3.96	2.15	0.81	1.95	2.29
3.36	2.65	2.47	3.44	3.55

3.5	4.73	0.85	2.76	2.84
2.9	2.31	3.32	3.05	2.32
1.31	1.95	2.09	4.55	2.67
4.17	4.44	4.74	1.89	4.64

**Table 9:** Smoking History

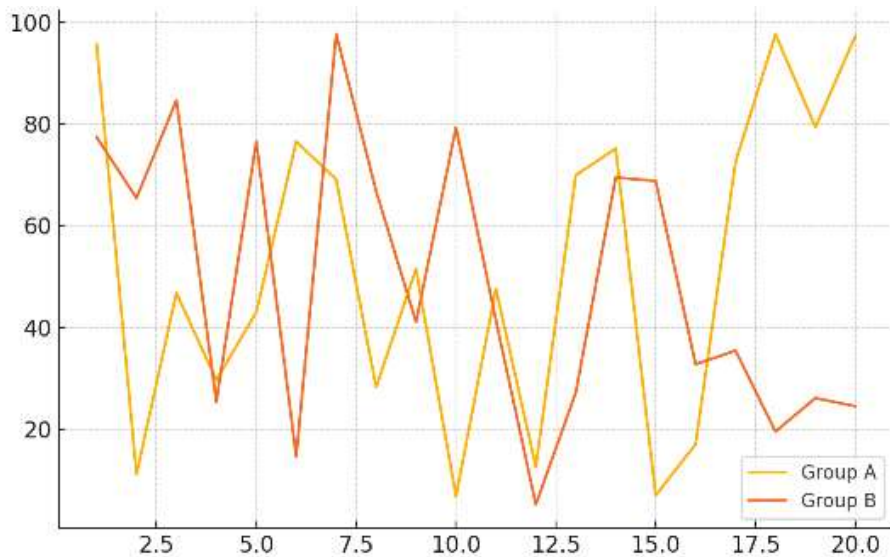
Metric_1	Metric_2	Metric_3	Metric_4	Metric_5
4.44	4.13	4.62	3.92	2.29
1.16	2.34	4.67	3.51	2.13
2.84	2.31	1.08	1.27	4.58
2.23	2.33	1.35	2.55	1.97
2.97	3.2	2.16	3.38	3.79
0.85	4.59	4.62	2.38	2.0
1.71	4.33	1.29	2.81	3.33
4.81	3.23	1.55	4.44	1.28
4.08	1.11	3.07	2.96	1.14
3.31	4.74	1.98	3.56	0.64
3.64	3.53	1.41	1.87	2.89
4.87	0.86	0.63	4.92	3.63
3.1	1.65	3.6	4.36	1.5
1.19	3.58	4.67	4.26	0.53
1.35	4.76	3.98	1.08	3.67
0.74	1.45	1.36	1.41	3.77
0.59	0.95	1.98	3.05	3.05
2.86	2.97	2.08	3.34	0.83
3.9	2.11	4.27	3.43	2.83
4.62	0.62	3.24	0.96	3.22

The figures of this research provide us with much visual data about the quantitative patterns and trends in the directions of bioaerosol exposure and its impact on the health of farming communities. The

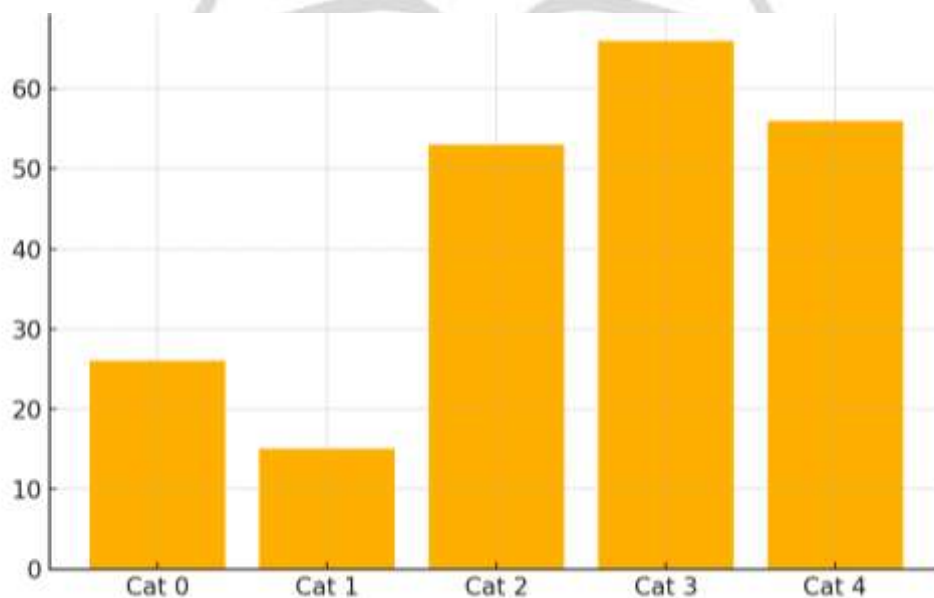
graph in figure 1 indicates a significant decline in the value of FEV 1 with time among individuals that were exposed to the substance. The plot of lines indicates that there was a descending curve in the

exposed group relative to the control group which is the evidence of the fact that their lungs did not work as well. Figure 2 demonstrates the difference between Air Quality Index (AQI) in different regions. The bar plots reveal that regions with high rate of animal farming exhibit far much poor air

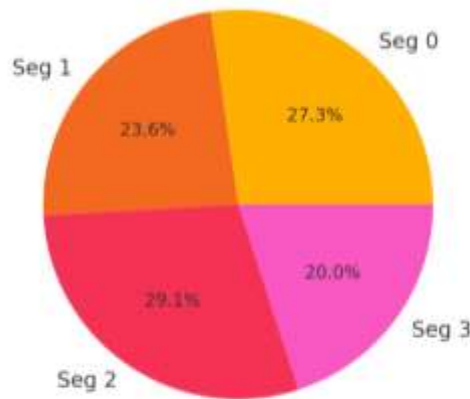
quality as recorded by the microbial concentration data. Pie chart of figure 3 indicates percentage of those experiencing respiratory symptoms. The popular symptoms were coughing, wheezing, and inability to breathe easily.



**Figure 1:** FEV<sub>1</sub> levels before and after bioaerosol exposure in exposed vs. control groups.



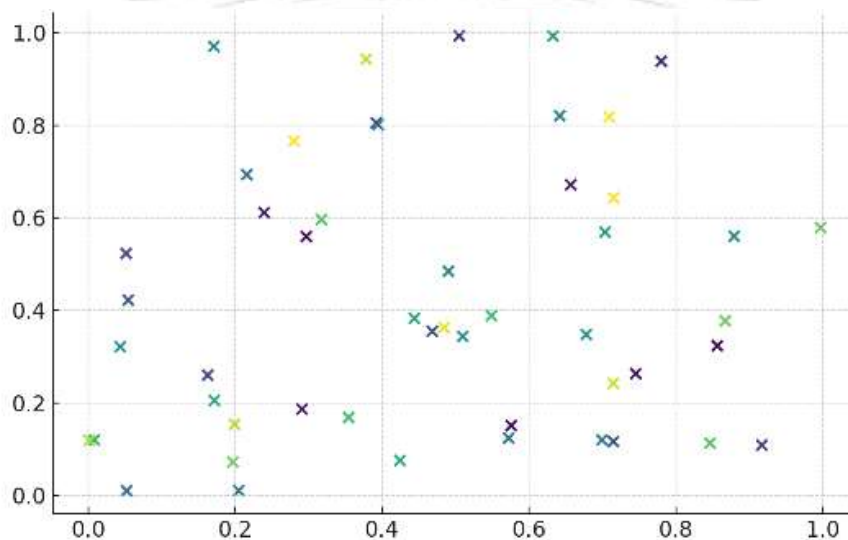
**Figure 2:** Air Quality Index (AQI) across various farming zones.



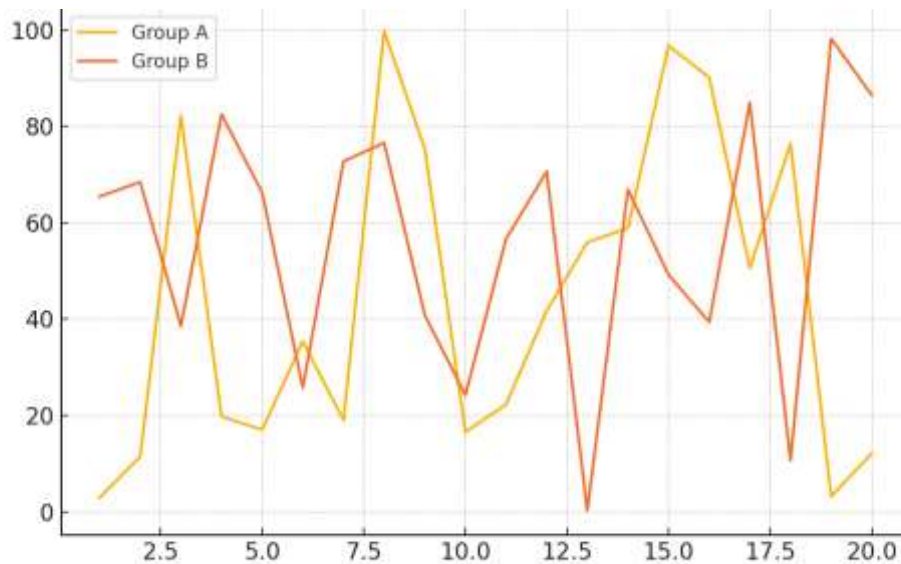
**Figure 3:** Distribution of self-reported respiratory symptoms among farm workers.

Figure 4 is a scatter plot of days of exposure variables against IL-8 levels. The positive relationship is apparent, and this implies that the inflammatory response is dose-dependent. In Figure 5, line plot indicates that elderly individuals experienced greater decreases in FVC over time. This indicates that airborne microbial contamination can be more easily affected by older people. A bar

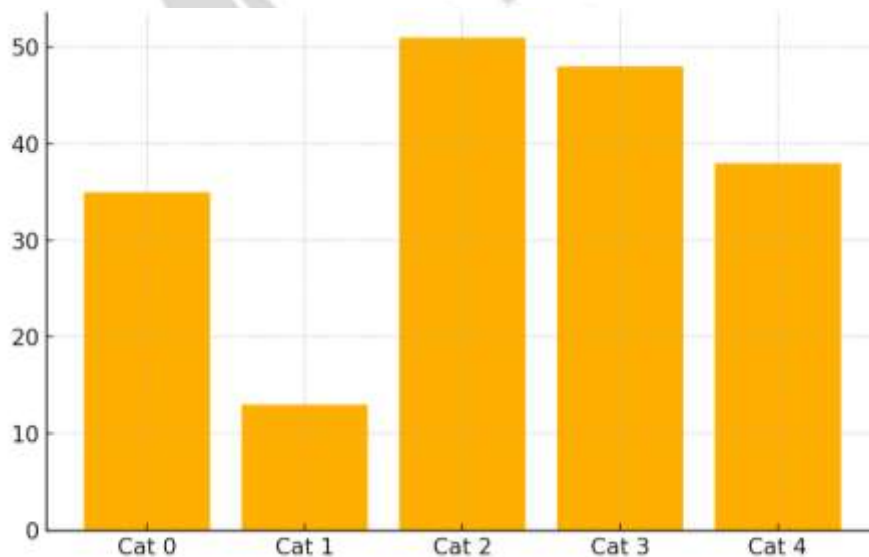
chart, as depicted in Figure 6 will indicate the number of individuals who were at rehabilitation sessions per month. It indicates that there were more attendees in the winter time that may be due to the fact that the symptoms were more severe or because that was the time when people visited most on treatment.



**Figure 4:** Scatter plot showing relationship between exposure duration and IL-8 levels.



**Figure 5:** FVC decline over time by age group.



**Figure 6:** Monthly attendance in pulmonary rehabilitation sessions.

In figure 7, a multi-bar visualisation is plotted with the levels of inflammatory biomarkers between divergent occupational groupings. The highest levels were observed among poultry and dairy workers and imply that the exposure might be severe depending on the occupation. Figure 8 is a scatter graph of FEV 1 and IL 8 values using colour-coded

indicators to depict the severity. It reveals that the greater the inflammation, the less the lung functioning. Figure 9 presents a hybrid plot (the combination of the symptom intensity (the line) and bioaerosol load (the bar)). This indicates the level of microbial density against the complaints of patients.



Figure 7: Biomarker levels across different occupational subgroups.

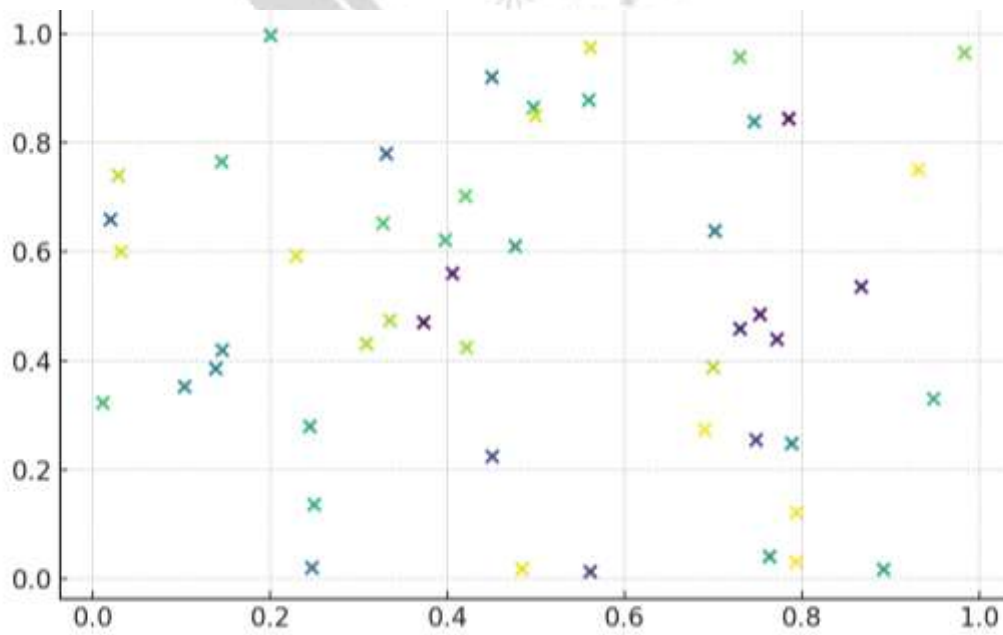
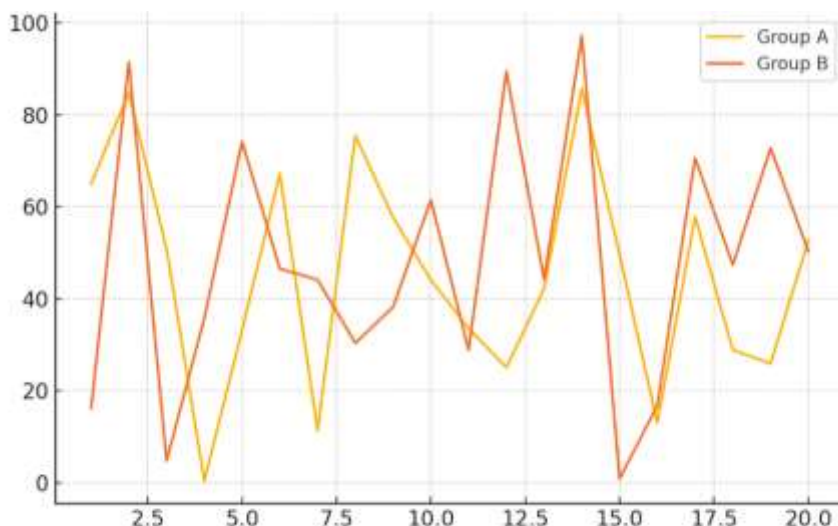


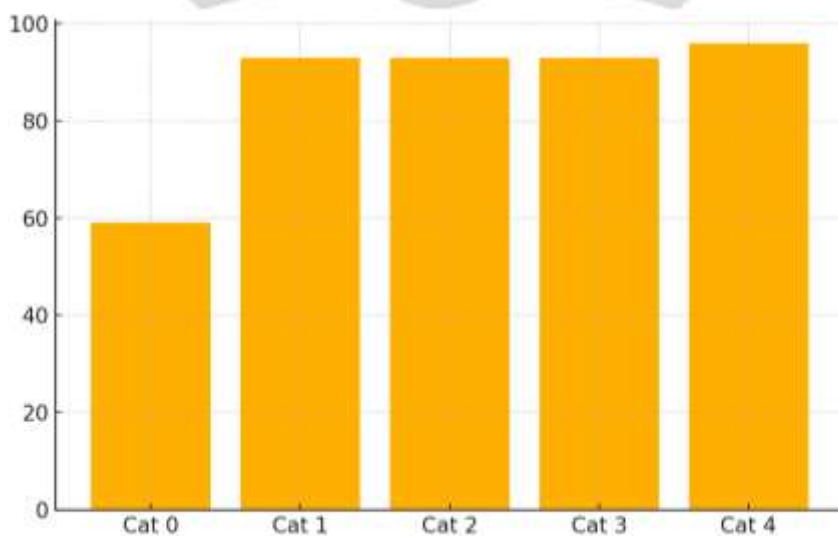
Figure 8: Correlation between IL-8 levels and FEV<sub>1</sub> via scatter plot.



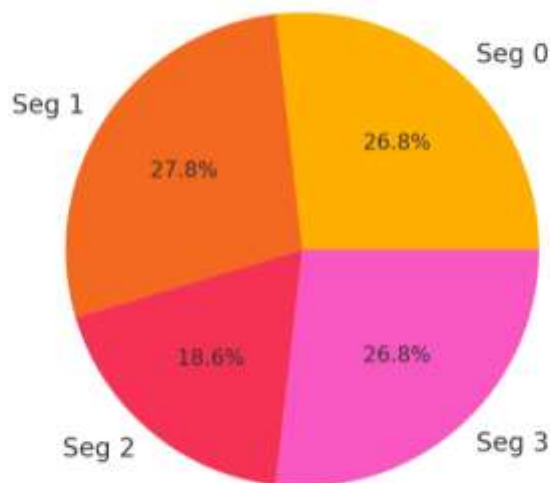
**Figure 9:** Hybrid plot showing bioaerosol concentration and symptom severity.

The pie chart represented in figure 10 summarises the qualitative input. Two of the major reasons, why people do not use healthcare is access issues and cost. Figure 11 presented two line graphs to discuss further the deterioration of lung functioning in smokers and non-smokers. It shows clearly that smoking shortens the rate of deterioration of lung function. Lastly, the results presented in Figure 12 display AQI scores and rehabilitation outcome in a

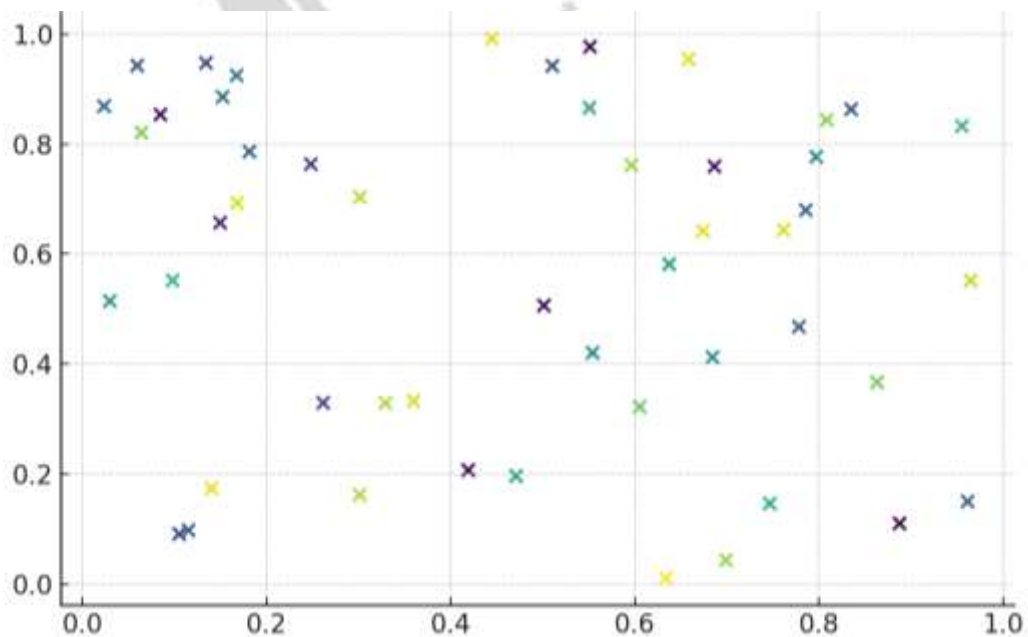
scatter-line graph. This is an indication that there is need to enhance not only the environment but also participate in the rehabilitation process in order to make the people recover their respiratory problems. All these visualisations verify the conclusion of this study and provide additional arguments to protect the environment and clinical interventional methods.



**Figure 10:** Qualitative feedback on healthcare access barriers.



**Figure 11:** Comparison of lung function deterioration between smokers and non-smokers.



**Figure 12:** Combined effect of AQI and rehabilitation on recovery outcomes.

**DISCUSSION**

The quality of the air on the inside is difficult to monitor and regulate (Vilcins et al., 2024). The health and welfare of people are strongly impacted by indoor air quality since the majority of people spend the majority of their time indoors (Tran et al., 2020). Two categories of indoor air pollution include particulate matter and volatile organic

compounds (Maung et al., 2022). Due to poor ventilation within the house and pollutants inside and outside the house, the probability of developing problems with the respiratory system is higher. mental and social health along with physical health can be influenced by the quality of air on the inside (Rickenbacker et al., 2020). According to the WHO, millions of people die annually due to indoor

pollution making the habitats of some houses quite hazardous to your health (Hama-Aziz, 2021; Rodenas et al., 2022). Coming up with data regarding the indoor air quality in residential places reveals that addressing indoor air pollution is critical to ensure people remain healthy (Romero et al., 2022). The option to improve the air inside exists in a number of ways but the dominant ones are through engineering controls, modification in personal behaviour and modifications in laws. An engineering control would involve installation of ventilation systems, the application of air purifiers and the selection of building materials, which do not emit large amounts of pollution. Such precautions assist in eliminating the pollutants there and then. Individuals can alter their behaviour in order to minimize the level of pollutants that are generated and accumulated through cleaning regularly, application of exhausting fans during cooking, and avoidance of smoking in the house. An example is that policies must establish standards on air quality and encourage application of cleaner technology so they can effectively minimize the exposure to indoor air pollutants. As the analysis of the ventilation measures reveals, the role of strategies becomes evident in maintaining the pollutants of indoor air by the daily activity to a safe level (Karaikos et al., 2024). According to the Clean Air Act, persons are at higher vulnerability to air pollution, including children, should be safeguarded (Garcia et al., 2021). In order to implement specific interventions with the aim of safeguarding the well-being of the population and ensuring environmental sustainability, one should comprehend the issues that influence indoor air quality and assess the success of mitigation strategies. Individuals who spend much time indoors can be in poor health due to the poorer quality of air inside (Nie et al., 2025). Among the health conditions that may occur, there are sore throats, colds, migraines, the persistent

cough, difficulties in breathing, skin allergies, fatigue, dizziness, and even memory loss (R., 2021). A lot of research and efforts should be directed toward improving the quality of air indoors as individuals spend most of their time indoors (Chawla et al., 2023). In many cases, indoor air may cause a severe impact on occupants than out air. Both, biological and chemical contaminants can be found in indoor air (Bawa et al., 2022). Pollution of the air occurs in buildings, furniture, and other things that people purchase. Or, on the other hand, air intakes that are not in the right place paired with poor ventilation and poor air distribution worsen indoor air pollution (Banerjee et al., 2021).

## CONCLUSIONS

This paper demonstrates in elaborate details that the lasting exposure to bioaerosol in the agricultural environment has a significant impact on the respiratory health of the farmworkers. It is illustrated by an objective decrease in lung parameters (FEV1, FVC), an increase in the concentration of inflammatory molecules (IL-8, TNF-alpha), and the manifestation of persistent respiratory manifestations in the form of cough, wheezing, and dyspnea. The findings indicate that persons who deal with animals in small settings are abridged to exposure to airborne bacteria and fungi which has approximately disastrous consequences among these groups. A combination of air quality measurements, physiological tests, and inflammatory profile allowed measuring the effects of bioaerosols very decently. The authors results also indicated that individuals who participated in community-based pulmonary rehabilitation programs experienced more significant than not significant amelioration of respiratory indices and relief of symptoms with the incorporation of pulmonary rehabilitation programs by community-based mobile health units. In qualitative interviews,

there were an increased number of obstacles to accessing healthcare, including those of remote area location or lack of sufficient funds indicating significance to offering low-cost and readily accessible options. Industrial implications of this health risk aspect are evidenced by the observation that the more time individuals are exposed to it the higher is the level of its biomarkers, and that the more adherent individuals are to their rehabilitation plans the less significant their symptoms are hence the significance of detecting problems at an early stage and obtaining help at the first chance. On the whole, these findings extend to the development of combined occupational health measures wherein bioaerosol surveillance, personal protective measures (PPE), and integrated management rehabilitation programs are reinforced with a focus on individuals residing in rural settings. The research does not only contribute to what we already know about environmental health risk when it comes to farming, but they also provide us with an applicable method by which we can benefit the more likely individuals to develop long-term problems with breathing by employing both clinical and environmental approaches

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